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Instrumented experiments aboard the frigate "WOLF".
Wolf II: Measurement results of the 5.5 kg TNT experiment in the crew aft sleeping compartment

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Summary

Within the framework of the research into the vulnerability of ships, an experimental investigation took place in 1989 aboard the frigate "WOLF" of the "Roofdierklasse" (PCE 1604 class) (Wolf, Phase II).

In this report the recordings of an instrumented experiment in the crew aft sleeping compartment are presented. During this experiment, a non-fragmenting charge of 5.5 kg TNT was initiated.

Samenvatting

In het kader van het onderzoek naar de kwetsbaarheid van schepen zijn in 1989 een aantal experimenten uitgevoerd op het fregat "WOLF" van de Roofdierklasse (PCE 1604 class) (Wolf, Fase II).

In dit rapport worden de meetresultaten gepresenteerd van een geïnstrumenteerde beproeving van het manschappen slaapcompartiment op het achterschip. Tijdens dit experiment werd een kale 5.5 kg TNT tot ontploffing gebracht.

CONTENTS

1 INTRODUCTION

In order to obtain quantitative as well as qualitative information on the effects of internal and external explosions on a frigate, a number of (instrumented) experiments were performed on the frigates "FRET" and "WOLF" (Figure 1). These are Roofdier class frigates, the former United States Navy PCE 1604 class, which were decommissioned by the Royal Netherlands Navy. A general overview of the Roofdier trials is given in Table 1.

Table 1 A general overview of the Roofdier trials

Fret I	June/September 1987	(v.d. Kasteele and Verhagen, 1989)
Wolf I	October/November 1988	(v.d. Kasteele and Zwaneveld, 1989)
Wolf II	September/October 1989	(Verhagen and v.d. Kasteele, 1992)

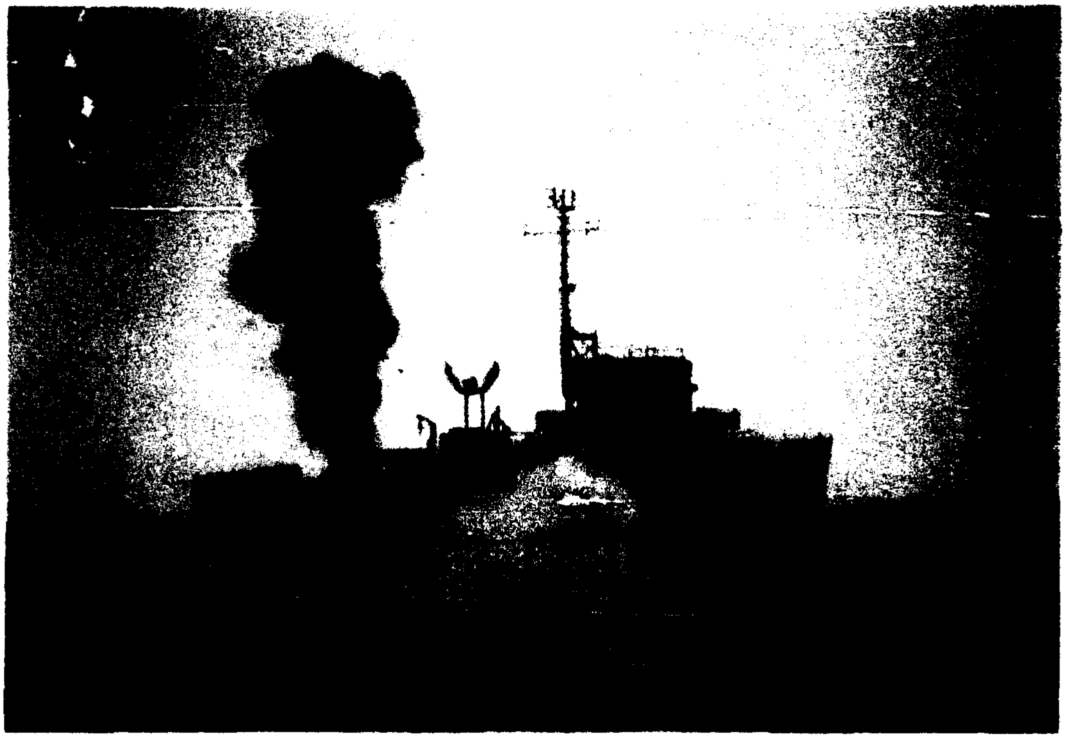


Figure 1 Wolf frigate

Pressure, strain, acceleration etc. were recorded during the Wolf Phase II bare charge experiments. These experiments were performed in the crew aft as well as the crew forward sleeping compartment. In the crew aft sleeping compartment, the 2, 5.5 and 15 kg TNT bare charge experiments were all performed on one day. The volume of this compartment was ±77 m^3, thus realizing a "charge density" of ±0.026, ±0.072 and ±0.20 kg/m^3.
The 3 and 12 kg TNT bare charge experiments were performed in the crew forward sleeping compartment also on one day. The volume of this compartment was ±105 m^3, thus resulting in a "charge density" of ±0.029 and ±0.11 kg/m^3.
During these Phase II experiments special attention was paid to the blast resistance of the watertight doors (i.e. the 2, 3 and 5.5 kg TNT experiments), the resistance of the structure (the 12 kg TNT experiment) and the rupture of structural elements (the 15 kg TNT experiment).

The results of the instrumented Wolf Phase II experiments presented conform to the previous reports dealing with the recordings of the Fret and Wolf Phase I experiments. Each report can be regarded as an independent report. It goes without saying that it is not within the scope of these reports to discuss the recordings in detail or even to compare the recordings with theoretical predictions. That will be an integral part of the reports as presented by van Erkel (1992).
Nevertheless, some additional information is given concerning the reliability of the presented recordings.

Due to the increased knowledge and experience gained from the Fret and Wolf Phase I trials, modified mounting and protection techniques were used during the Wolf Phase II trial. It is for this reason that a separate report deals with the general background information as well as the mounting and protection methods used. For the sake of completeness, a description is also given of the registration equipment and the signal analysis system used.

This report deals with the bare 5.5 kg TNT experiment in the crew aft sleeping compartment.

Some general remarks on the experiment are given in Chapter 2, as well as some specific information of the charge used. In the following chapters, the recordings are presented.
Offset elimination was carried out. The time axis used was related to the moment of ignition of the charge (t=0).

Because the 2 kg, 5.5 kg and 15 kg TNT experiments in the crew aft sleeping compartment were performed in one day, there was no time available between the experiments for the technicians to

adjust the settings of the registration equipment. Instead, a general setting was used for these experiments based on the maximum charge (15 kg TNT) to be used on that particular day. This however had an effect upon the signal-to-noise ratio. The settings of only a few signals could be adjusted between the experiments. Moreover, damaged transducers could not be repaired between the experiments. The damage to the frigate, due to the 2 kg TNT experiment earlier that day in the same compartment, was not repaired either.
Some abbreviations often used are BHD (Bulkhead), SB (Starboard), PS (Portside) and CL (Centre line frigate).

2 DESCRIPTION OF THE EXPERIMENT

2.1 Objective of the experiments

One of the objectives of the ROOFDIER trials is the validation of the computer code "DAMINEX" as developed by the Weapon Effectiveness Department of the TNO - Prins Maurits Laboratory.
The DAMINEX code determines the structural damage to a frigate due to internal blast. A number of theoretical assumptions were made during the development of this code, which however may have a large influence on the final simulation results.
In general, the damage caused by the experiments is registered visually. It is for this reason that a lack of quantitative information is still apparent. The specific objective of the ROOFDIER trials is to gain more quantitative as well as qualitative information by performing well-documented experiments. This information will be used to validate (or modify) the DAMINEX code.

2.2 Experimental set-up

Two crew sleeping compartments were chosen by the Weapon Effectiveness Department for the instrumented experiments: the crew forward sleeping compartment and the crew aft sleeping compartment. These two compartments correspond with the sleeping compartments used during the FRET experiments. As a consequence, these experiments can be compared with the FRET experiments, although during the latter, (bare) charges of 8 kg and 12 kg TNT were used.

The crew aft sleeping compartment (height: 2.2 m, length: 4.3 m, width: 7.2 m - 9.4 m) was cleared as much as possible of all obstacles. A venting hole (diameter 40 cm) was created in the centre of the SB hull in the compartment to simulate the hull's penetration by the warhead. The damage due to the 2 kg TNT experiment earlier that day could not be repaired between these two

experiments. As a consequence, the adjacent compartments were connected with the experiment compartment by ruptures in the wall/floor and wall/ceiling.

The charge used during this particular experiment was a cylindrical cast charge (L/D=1, D=153 mm) adjusted with two rectangular blocks of 500 grams TNT (45.6 x 70.8 x 105.0 mm^3) resulting in a charge of 5.5 kg TNT. The charge was ignited at its centre with one electrical detonator (No. 8) and a booster of three RDX cartridges (L/D=1, D=50 mm). The geometry of the charge is shown schematically in Figure 2. The charge was located just in between the two doors in the crew sleeping compartment at midheight. An impression of the set-up is given in Figure 3. Note that the location of the charge does not correspond with the 2 kg TNT experiment.

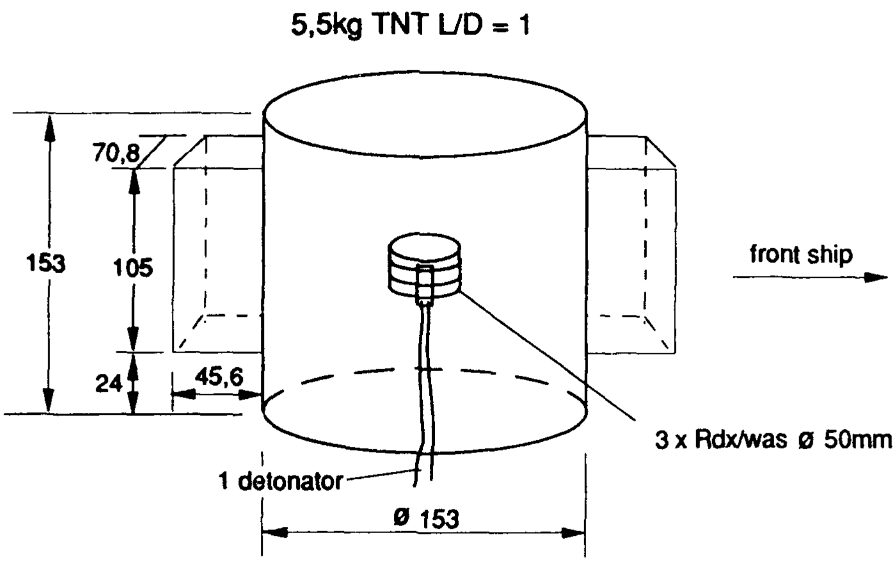


Figure 2 Geometry of the charge

Figure 3 Impression of the experimental set-up and charge

3 PRESSURE MEASUREMENT

3.1 Position of the pressure transducers

To measure the overpressure, eight piezo-electric pressure transducers B1-B8 were used, all mounted in the experiment compartment. B1 and B2 were mounted on the hull of the frigate whereas B3-B8 were flush mounted on the bulkheads. It must be noted that transducer B1 was located in the hull in the vicinity of the 40 cm diameter venting hole. All transducers were mounted at about mid-height in the compartment. The positions of the transducers are summarized in Table 2 and shown schematically in Figure 4.

Table 2 Position of pressure transducers

Device	Height	Mounting position	
B1 (1)	115 cm	on hull SB,	155 cm from BHD 78
B2	115 cm	on hull PS,	155 cm from BHD 78
B3	114 cm	on BHD 78,	35 cm from CL
B4	114 cm	on BHD 78,	176 cm from CL
B5	114 cm	on BHD 78,	328 cm from CL
B6	115 cm	on BHD 71,	368 cm from CL
B7	114 cm	on BHD 71,	259 cm from CL
B8	114 cm	on BHD 71,	102 cm from CL

(1) in vicinity of the venting hole

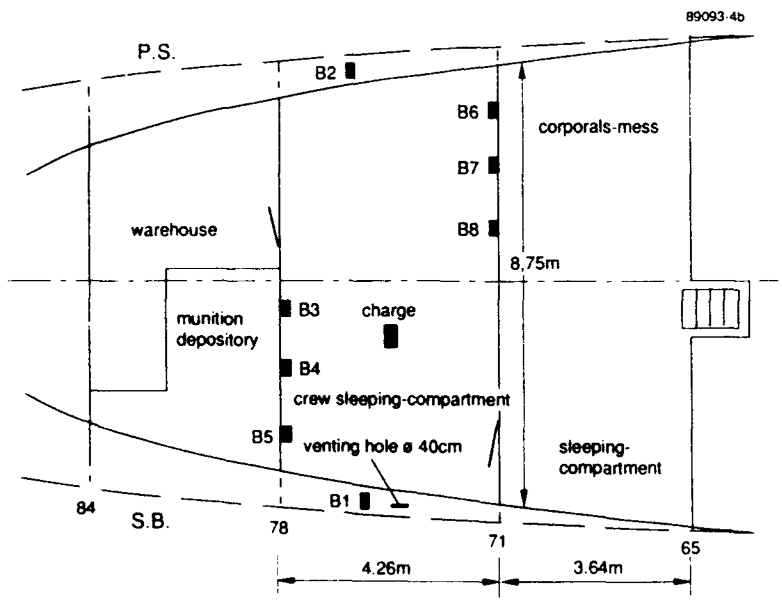


Figure 4 Schematic illustration of the positions of the pressure transducers

3.2 Discussion of the pressure measurements

In order to get an impression of the accuracy of the recordings as presented in Figures 5-7, the first peak pressure and the arrival time of each signal were determined and gathered in Table 3.

Due to the charge geometry, a direct comparison with theoretical predictions was not possible. All the charge used was modelled as a spherical charge which is ignited in the centre. With these simplifications, the theoretical predictions of the maximum (face-on) peak pressure and the arrival time of the shock front could be determined with Baker (1983, Figures 2.45 and 2.46). These predictions are also included in the table.

From this table it appears that the experimental arrival time generally agrees reasonably well with the theoretical prediction. Regarding the peak pressures, it appears that some of the experimental values correspond with the theoretical vaiues, although other devices show an overshoot of the theoretical value by up to a factor 4.

Table 3 Comparison of experimental and theoretical (first) peak pressure and arrival time

Device	d(D,C)	Z	Peak pressure		Arrival time	
			Exp.	Theor.	Exp.	Theor.
	[m]	[$m/kg^{1/3}$]	[kPa]	[kPa]	[ms]	[ms]
B1	3.15	1.78	893	1021	2.9	2.6
B2	5.35	3.03	583	195	7.2	6.6
B3	2.35	1.33	4220	1773	1.2	1.4
B4	2.30	1.30	8492	1793	1.1	1.4
B5	3.10	1.76	770	1062	1.9	2.6
B6	5.22	2.96	592	209	6.1	6.4
B7	4.25	2.41	552	403	4.5	4.6
B8	3.00	1.70	1007	1150	2.3	2.3

d(D,C) : distance between Device and Charge

Z : scaled distance [$m/kg^{1/3}$]

Theoretical values for a centrally ignited, spherical charge (Baker, 1983, Figures 2.45 and 2.46).

It must be noted that the devices show no symmetry with respect to the charge, therefore it is very difficult to compare the devices with each other. A factor 2 difference in peak pressure is found between B3 and B4, although these transducers are placed at almost identical distances from the charge.

Devices B1, B5 and B8 (placed at approximately 310 cm from the charge) show some resemblance although their experimental arrival times show a discrepancy of up to 1 ms.
Note that transducer B1 again shows a negative value shortly (5 ms) after the shock wave reached this sensor, comparable with the 2 kg TNT experiment. It appears that some of the signals drift in time which may be due to temperature. The simplifications made for the theoretical predictions did not hold. The discrepancy in the response of the devices can only be made plausible by taking into account the geometry of the charge and the way the charge was ignited. However, the pressure recordings as presented in this chapter seem to be reliable.

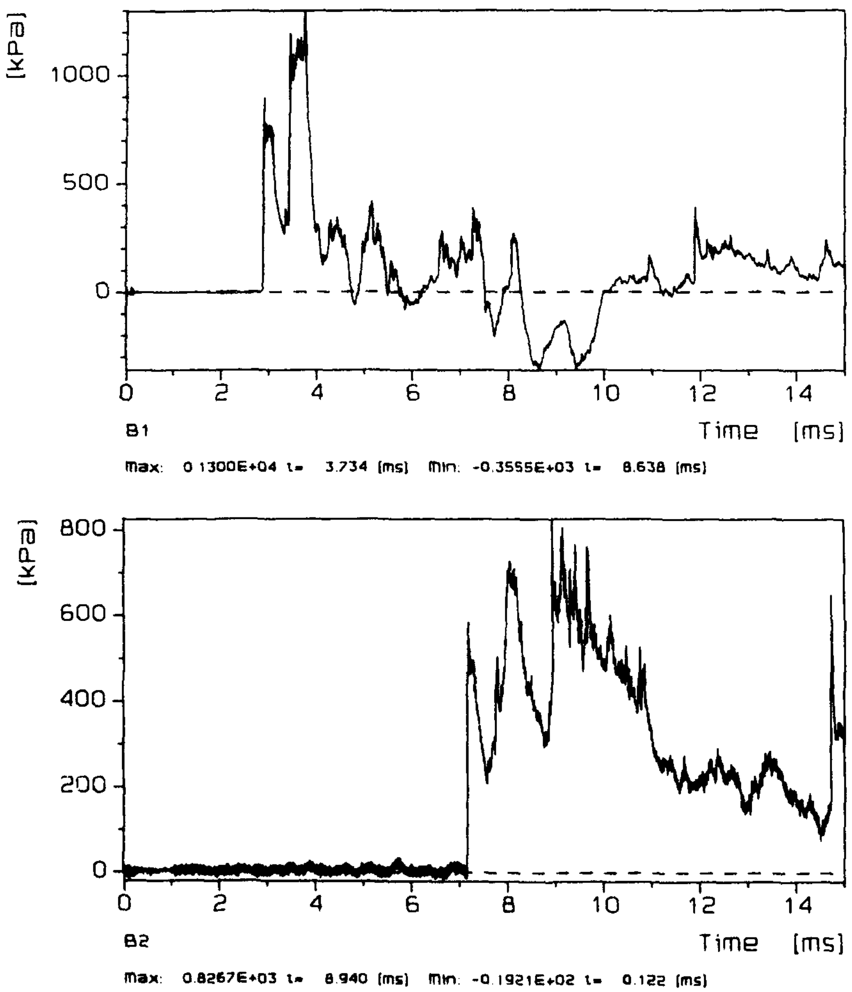


Figure 5 **Pressure signals B1 (SB hull) and B2 (PS hull)**

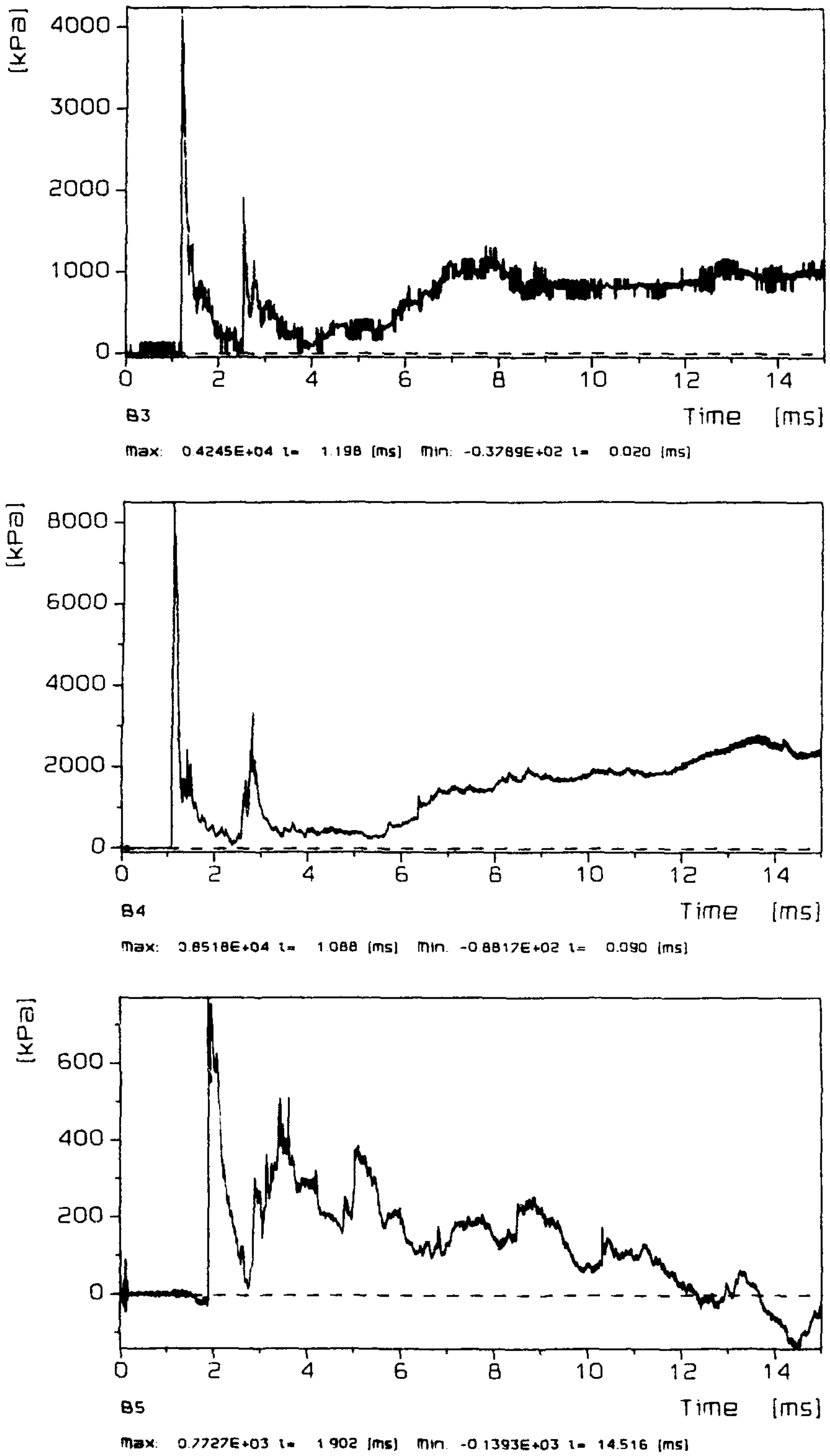


Figure 6 Pressure signals B3, B4 and B5 (BHD 78)

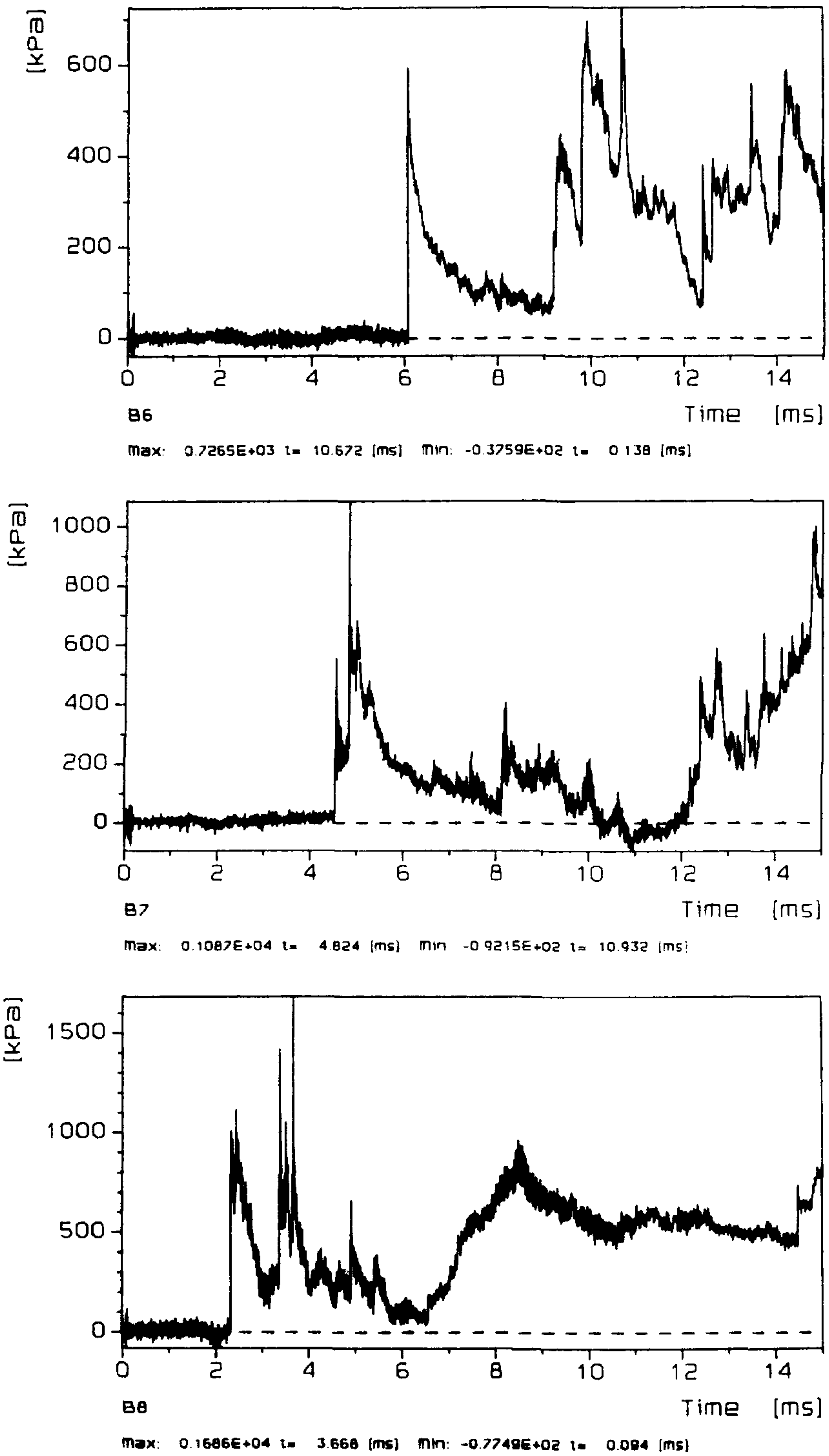


Figure 7 **Pressure signals B6, B7 and B8 (BHD 71)**

4 QUASI-STATIC PRESSURE MEASUREMENT

4.1 Position of the quasi-static pressure transducers

The quasi-static pressure was registered with piezo resistive transducers at seven different locations (Q1-Q7). Two transducers (Q1, Q2) were placed in the crew aft sleeping compartment (where the experiment took place). The other five transducers were placed in the neighbouring compartments, i.e. three transducers (Q3, Q4, Q5) in the corporals' sleeping quarters/mess, one (Q6) in the munition depository and one (Q7) in the warehouse. The positions of the transducers are summarized in Table 4 and shown schematically in Figure 8.

Table 4 Position of the quasi-static pressure transducers

Device	Height	Position
Q1(1)	125 cm	15 cm in front of the SB hull, experiment compartment
Q2	127 cm	17 cm in front of the PS hull, experiment compartment
Q3	118 cm	246 cm from SB, on BHD 65, corporals' sleeping quarters/mess
Q4	113 cm	305 cm from PS, on BHD 65, corporals' sleeping quarters/mess
Q5(2)	115 cm	200 cm behind door BHD 71, hull SB, corporals' sleeping quarters/mess
Q6	113 cm	141 cm from BHD 78, munition depository
Q7	113 cm	160 cm from BHD 78, warehouse

(1) in vicinity of venting hole

(2) membrane direction BHD 65 (face off)

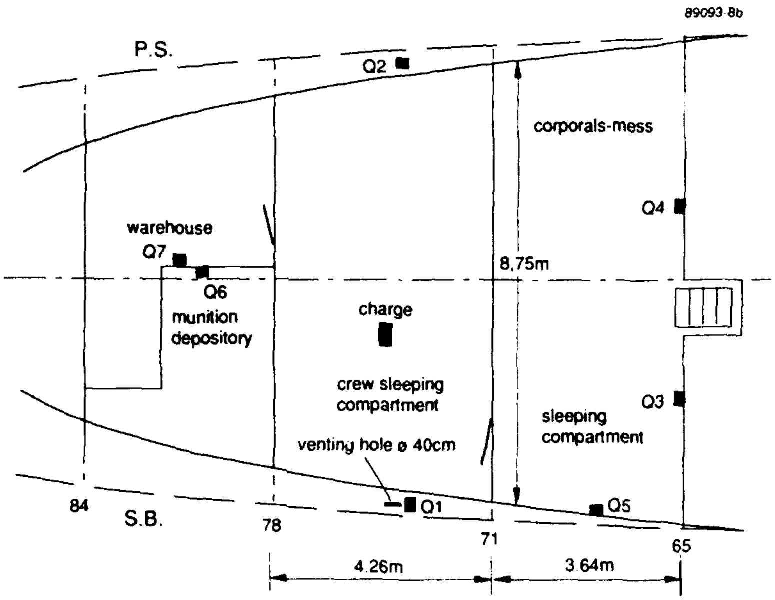


Figure 8 Schematic illustration of the position of the quasi-static pressure transducers

4.2 Discussion of the quasi-static pressure measurements

The recorded quasi-static pressures are presented in Figures 9-12.

Keeping in mind that there are no obstacles in the experiment compartment, the main difference in the Q1 and Q2 signals, the decay of the pressure, may be attributed primarily to the rupture of the upper deck. Additionally, the venting hole near device Q1 and the location of the charge may also influence this decay behaviour.

Devices Q3, Q4 and Q5 were mounted in the corporals' mess and sleeping quarters, which was one compartment. Walls etc. were removed before the experiments took place. This compartment is connected to the experiment compartment only by the door in BHD 71. The pressure in the compartment may be due to leakage of the door during the experiment. Note that the membrane of Q5 is in the direction of BHD 65. It appears that Q4 and Q5 show a close resemblance, while Q3 differs considerably. This may be attributed to the location of device Q3: behind the door in

BHD 71. This behaviour corresponds with the recordings of the previous 2 kg TNT experiment in this compartment.

The munition depository (Q6) has no direct connection with the experiment compartment, this compartment can only be reached from the upper deck. The pressure recorded in this compartment is due to a rupture in the bulkhead near the floor.

The warehouse (Q7) can be reached from the experiment compartment by a door which may have leaked during the experiment.

In Table 5, the arrival time T_a, the maximum pressure P_{max} and time T_{max} are summarized.

Table 5 Quasi-static pressure measurement

Device	T_a [ms]	P_{max} [kPa]	T_{max} [s]
Q1	2.8	210	0.05
Q2	7.4	250	0.05
Q3	8.0	15	0.2
Q4	9.0	32.5	0.39
Q5	9.3	30	0.42
Q6	4.0	65.7	0.30
Q7	16.0	53	0.38

A comparison with theoretical values is only possible for Q1 and Q2, mounted in the experiment compartment. According to Baker (1983, Figure 3.15), a quasi-static pressure of 300 kPa will be found, based on 5.5 kg TNT and a compartment volume of 77 m^3. The Weibull distribution gives 340 kPa. Comparing these values (300 kPa, 340 kPa) with the measured peak values of Q1 and Q2 (210 kPa and 250 kPa) shows a rather close resemblance, keeping in mind that a part of the pressure is leaked through the ruptured deck to the adjacent compartments and through the venting hole out of the experiment compartment.

Comparing the arrival time of device Q1 and Q2 with the arrival time of the pressure transducers B1 and B2, as summarized in Table 3, shows a close resemblance.

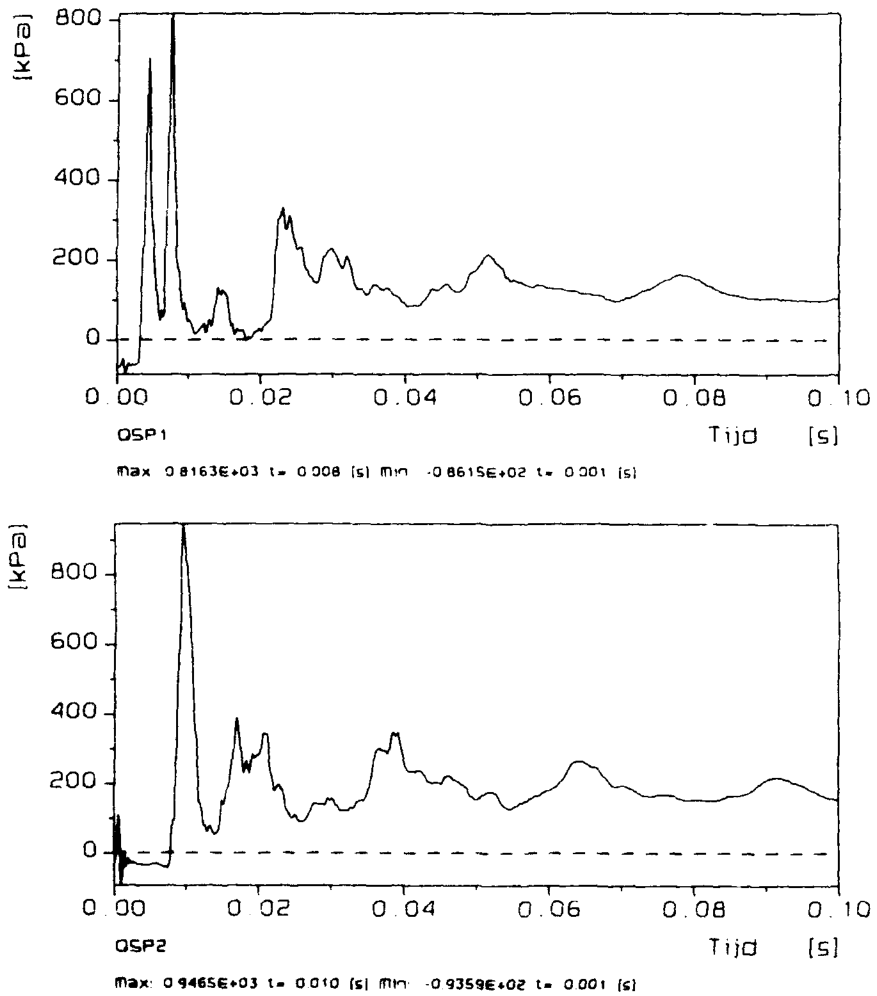


Figure 9 Quasi-static pressure signals Q1 and Q2 (experiment compartment)

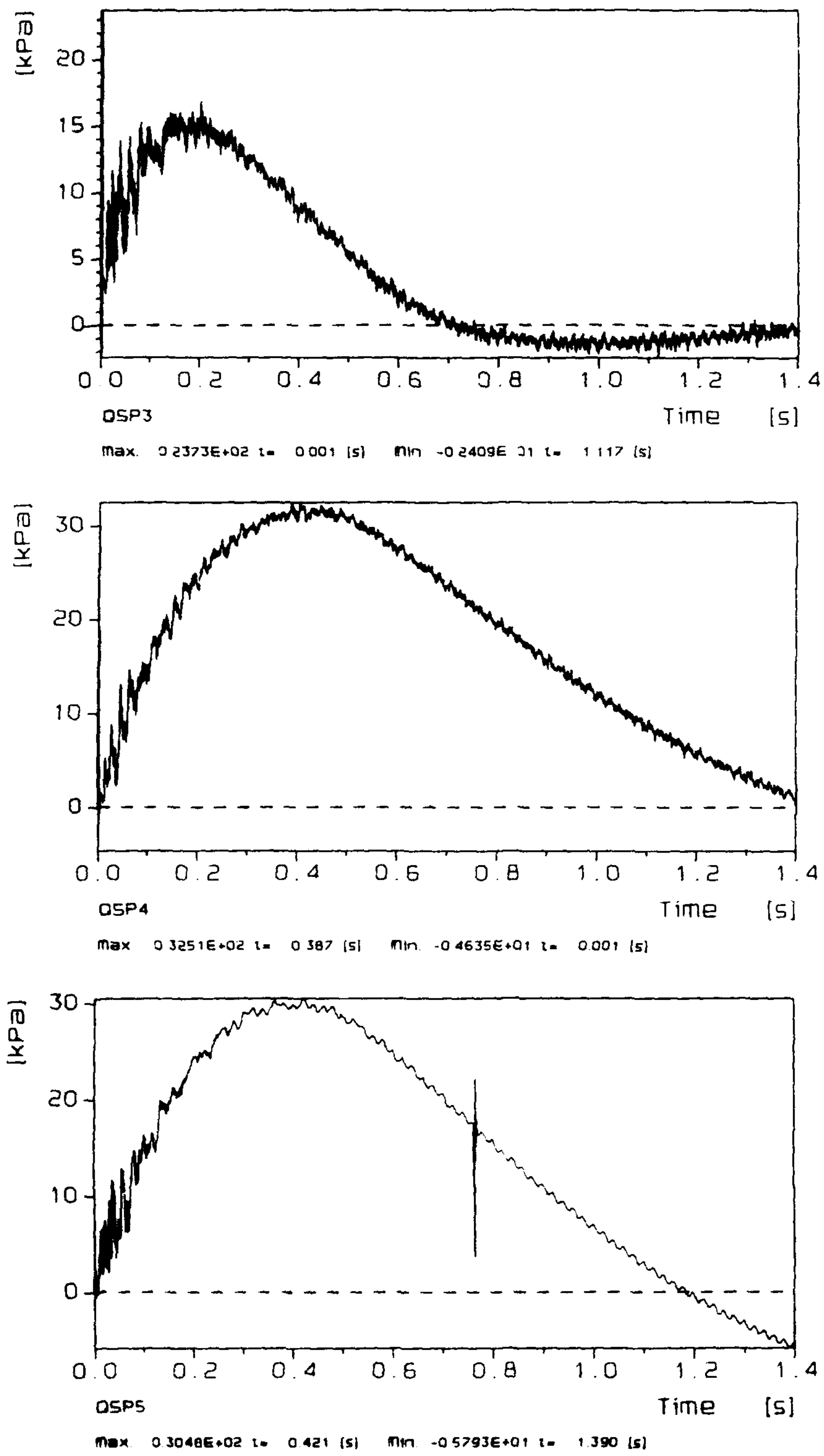


Figure 10 Quasi-static pressure signals Q3, Q4 and Q5 (corporals' mess and sleeping compartment)

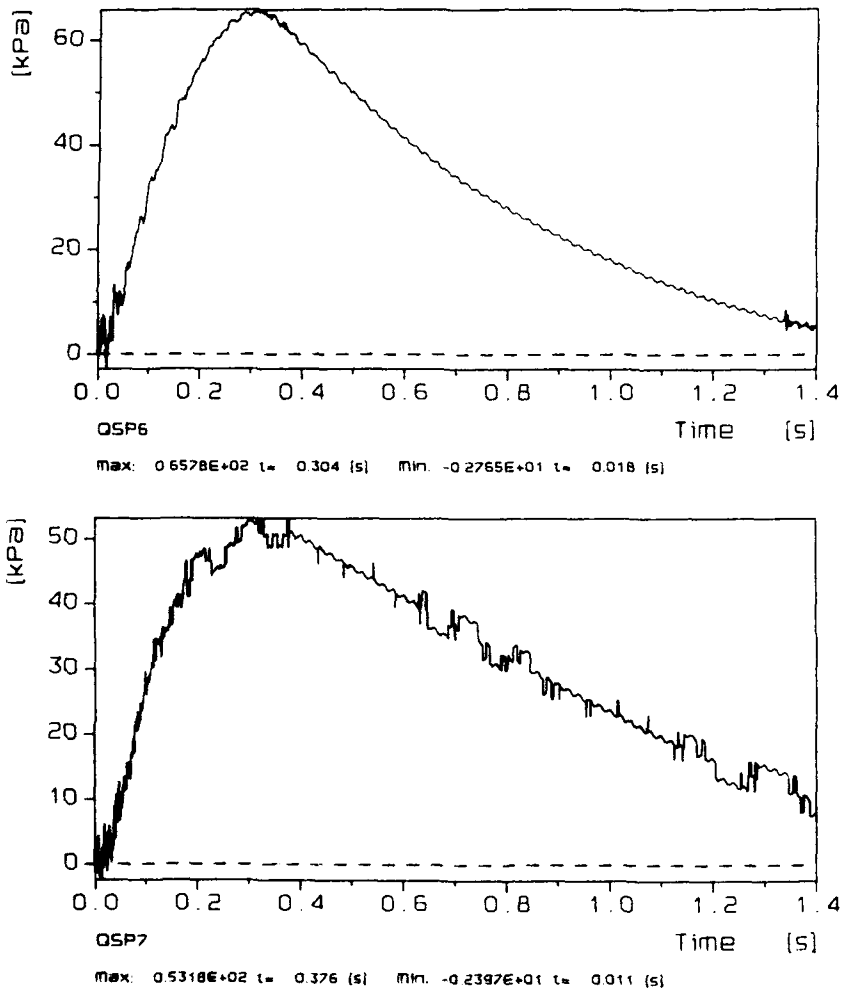


Figure 11 Quasi-static pressure signals Q6 (munition depository) and Q7 (warehouse)

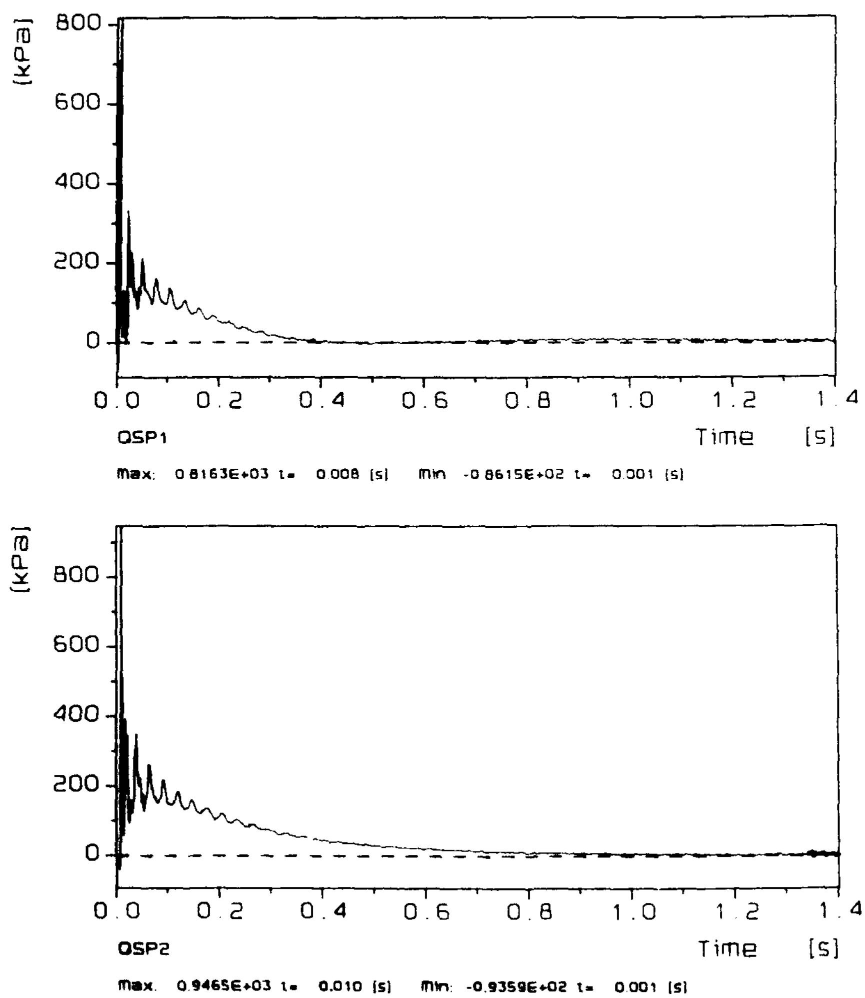


Figure 12 Quasi-static pressure signals Q1 and Q2 (experiment compartment)

5 STRAIN MEASUREMENT

5.1 Position of the strain gauges

The strain was measured using 2% and 10% strain gauges in twenty-two positions (S1-S22) during the experiments. Some of strain gauges were placed singly, while others were placed in pairs, opposite each other.
The positions of the strain gauges are summarized in Tables 6-8 and shown schematically in Figures 13-16; a subdivision has been used.

To describe and visualize the location of the strain gauges, the following notation is used:

: 2% strain gauge, single, front side

: 2% strain gauge, single, back side

d : 2% strain gauge, double, both sides

: 10% strain gauge, single, front side

: 10% strain gauge, single, back side

d : 10% strain gauge, double, both sides

The "front side" or "back side" description is related to the plane of view as shown in the figures.

Table 6 Position of the strain gauges on the hull (all in experiment compartment)

Device	Range	Height	Mounted on:
S1	2%	105.0 cm	Frame 74, SB
S2	2%	104.0 cm	Frame 74, PS

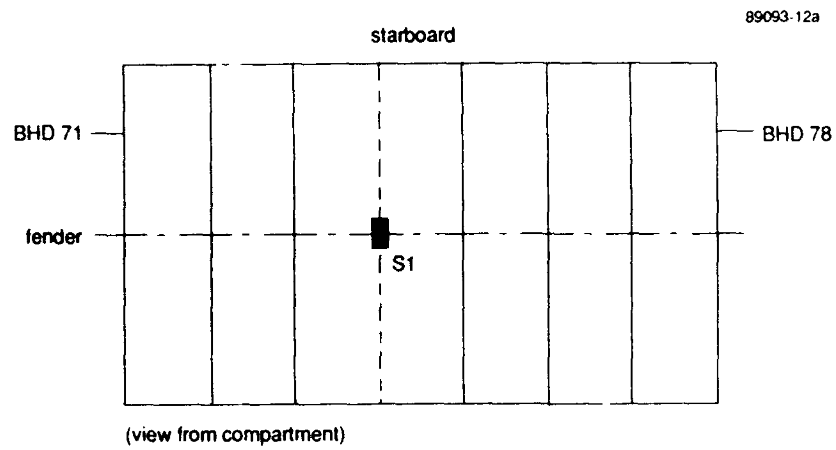


Figure 13 Schematic illustration of strain gauge position S1 (SB)

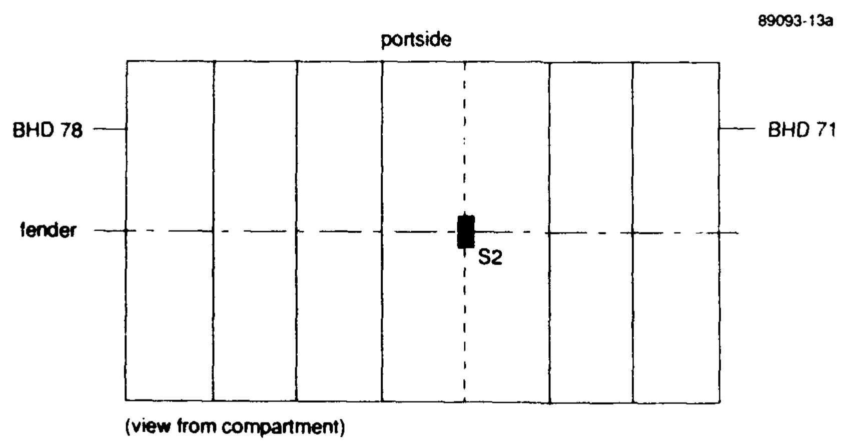


Figure 14 Schematic illustration of strain gauge position S2 (PS)

Table 7 Position of the strain gauges on BHD 71

Device	Range	Opposite	Height	Mounted on:
S3	10%	S22	80 cm(2)	centre door
S4(1)	10%	---	114 cm	wall, back side stiffener
S5	2%	S6	114 cm	10 cm beside stiffener
S6(1)	2%	S5	113 cm	10 cm beside S4
S7	10%	S8	30 cm	on stiffener
S8(1)	10%	S7	30 cm	wall, back side stiffener
S9	2%	S10	30 cm	wall, 10 cm beside stiffener
S10(1)	2%	S9	30 cm	wall, 10 cm beside S8
S11(*)	10%	S12	6 cm	wall, 10 cm beside stiffener
S12(1)	10%	S11	6 cm	wall
S13	2%	---	73 cm(3)	on stiffener
S22(1)	10%	S3	80 cm(2)	centre door

(1) in experiment compartment

(2) from bottom side door

(3) beneath ceiling (J-deck)

(*) malfunctioned during the 2 kg TNT experiment

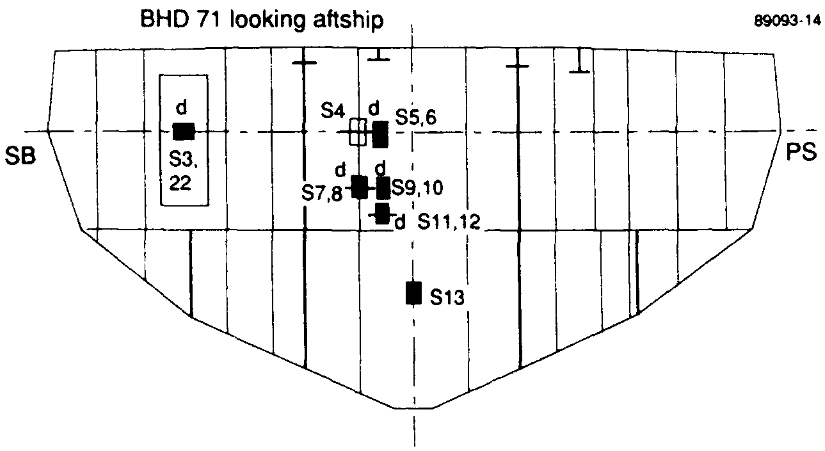


Figure 15 Schematic illustration of strain gauge positions on BHD 71

Table 8 Position of the strain gauges on ceiling and upper deck

Device	Range	Opposite	Mounting place:
S14	10%	S15	see S15, on deck
S15(1)	10%	S14	28 cm from BHD 78, 10 cm PS from CL
S16	10%	S17	see S17, on deck
S17(1)	10%	S16	101 cm from BHD 71, 135 cm from PS girder
S18(*)	10%	S19	see S19, on deck
S19(1)	10%	S18	15 cm from BHD 71, 40 cm from PS girder
S20	10%	S21	see S21, on deck
S21(1)	10%	S20	15 cm from BHD 71, 40 cm from SB girder

(1) in experiment compartment

(*) malfunctioned during the 2 kg TNT experiment

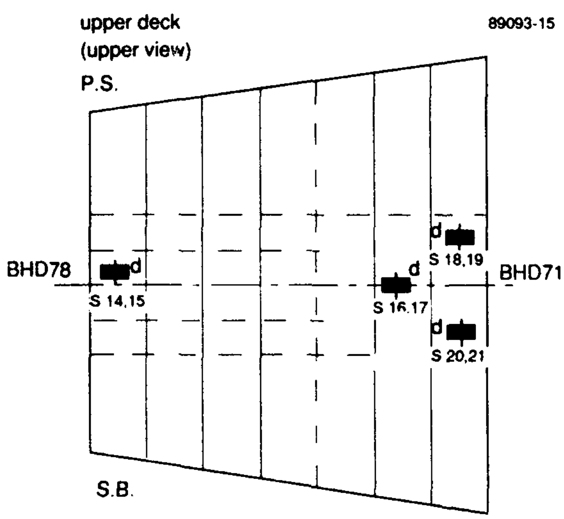


Figure 16 Schematic illustration of strain gauge positions on ceiling and upper deck (J-deck) of explosion compartment

5.2 Discussion of the strain measurements

The strain signals are shown on two different time-scales, i.e. in Figures 17-21 up to 300 ms; in Figures 22-26 up to 3 s. Opposite-mounted strain gauges are depicted in one figure, enabling a better understanding of the behaviour.
Strain gauge S6 malfunctioned after 10 ms, while S7 malfunctioned from the start. S10 generated a small response which seems to be not very realistic. The S11 signal is omitted due to a malfunction during the experiment. S18, which malfunctioned during the 2 kg TNT experiment, shows a response during this experiment, although the initial phase (as well as the initial phase of S19) shows some distortion.
From these recordings it appears that a number of signals show an elasto-plastic deformation (for instance, S1, S2, S22, S4, S12, S14 and S15, S16 and S17, S18 and S19, S20 and S21), while the remaining strain gauges record elastic deformations. Nevertheless, some of the latter ones show a permanent deformation which may be due to plastic deformation of another part of the structure and cannot be regarded as offset or drift.
From the figures presenting two opposite-mounted strain gauges, it appears that only S3 and S22 were in 'anti-phase'. Note that this couple was glued on the door in BHD 71. The remaining couples of strain gauges recorded 'in-phase' behaviour. This 'in-phase' response behaviour can be explained as follows: the plate is part of the girder and acts as one of the flanges. Consequently, a bending vibration in the girder is observed as an 'in-phase' vibration in the plate near the girder.

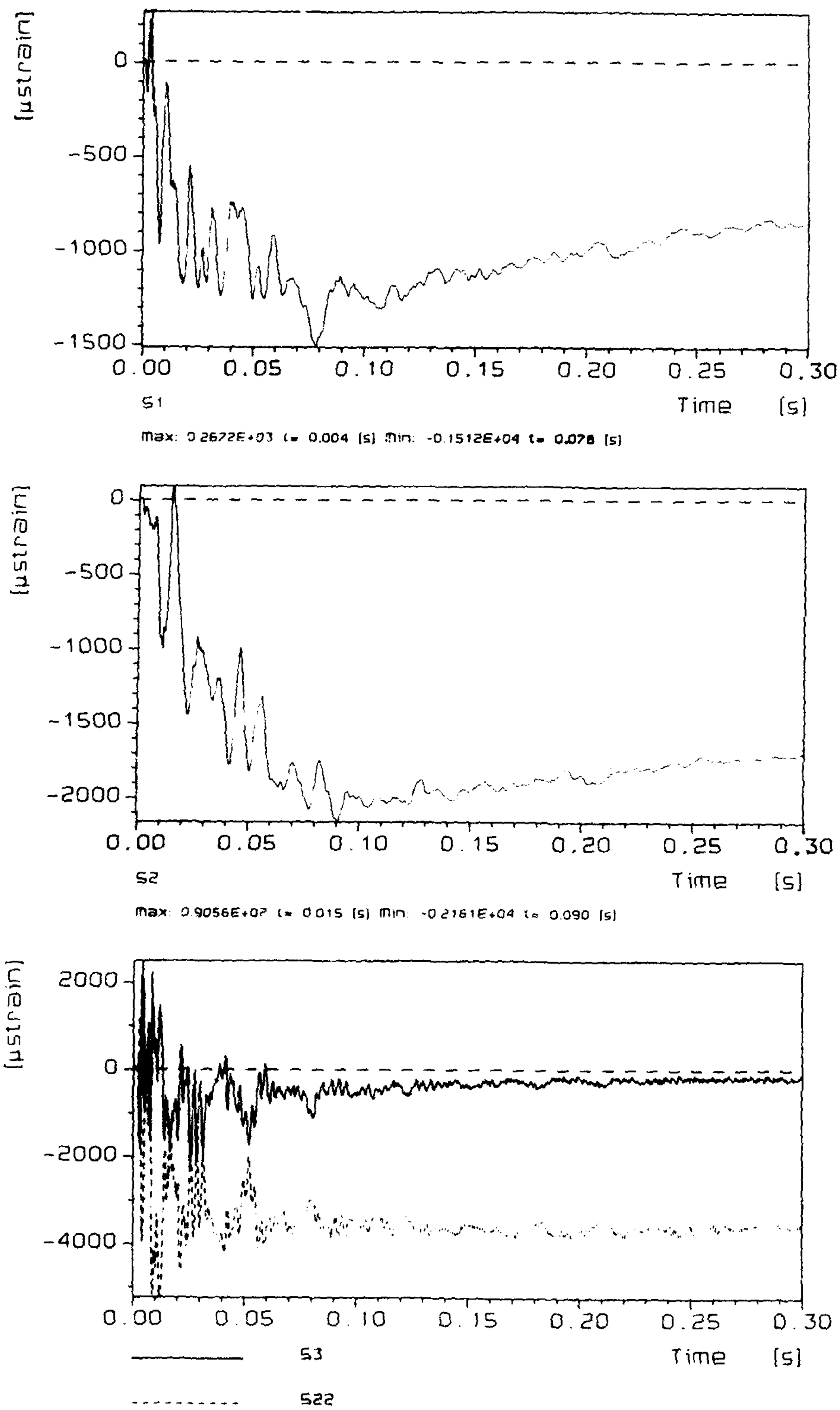


Figure 17 Strain gauge response S1, S2 (hull experiment compartment), S3 and S22 (BHD 71) (300 ms base)

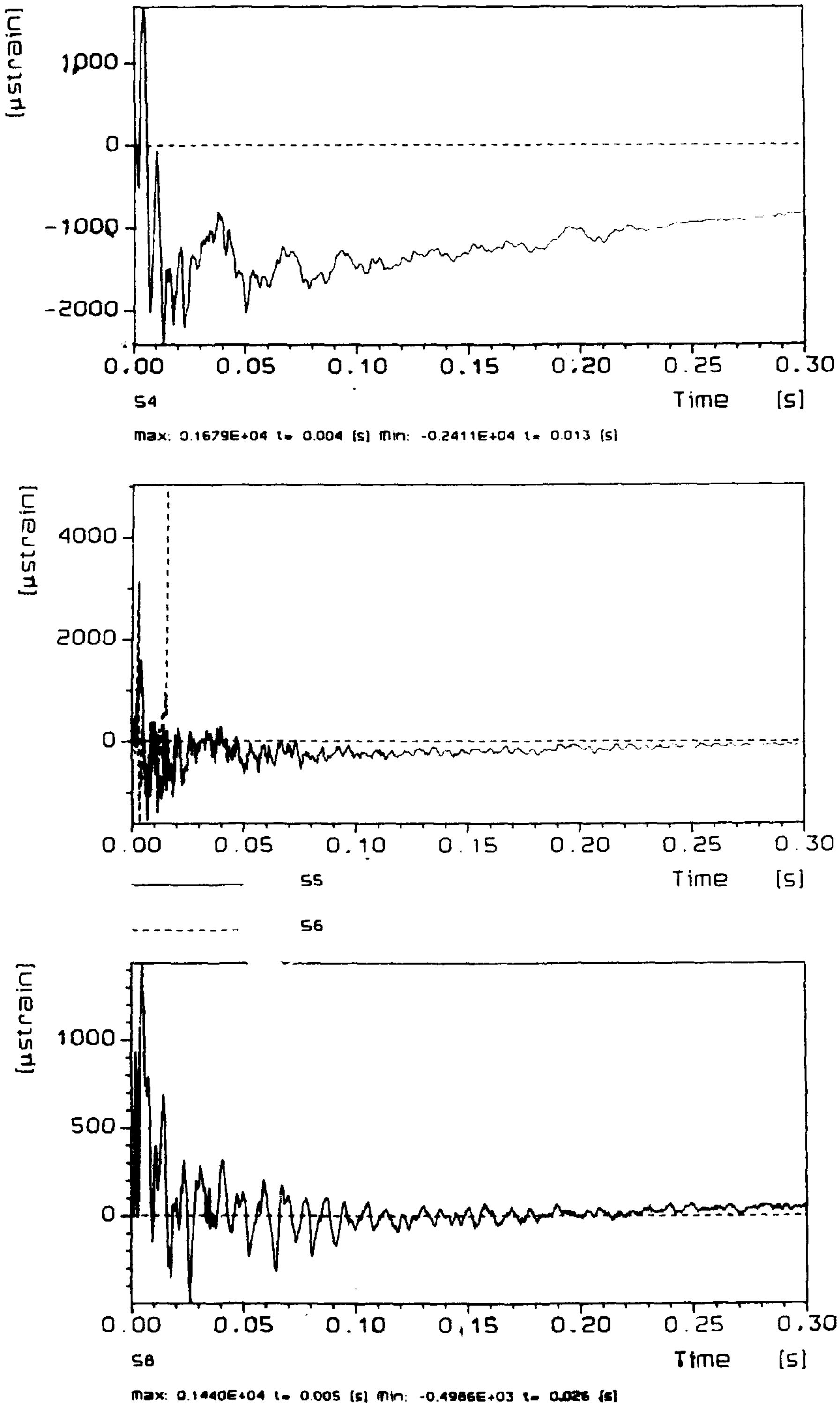


Figure 18 Strain gauge response S4, S5 and S6, S7 and S8 (BHD 71) (300 ms base)

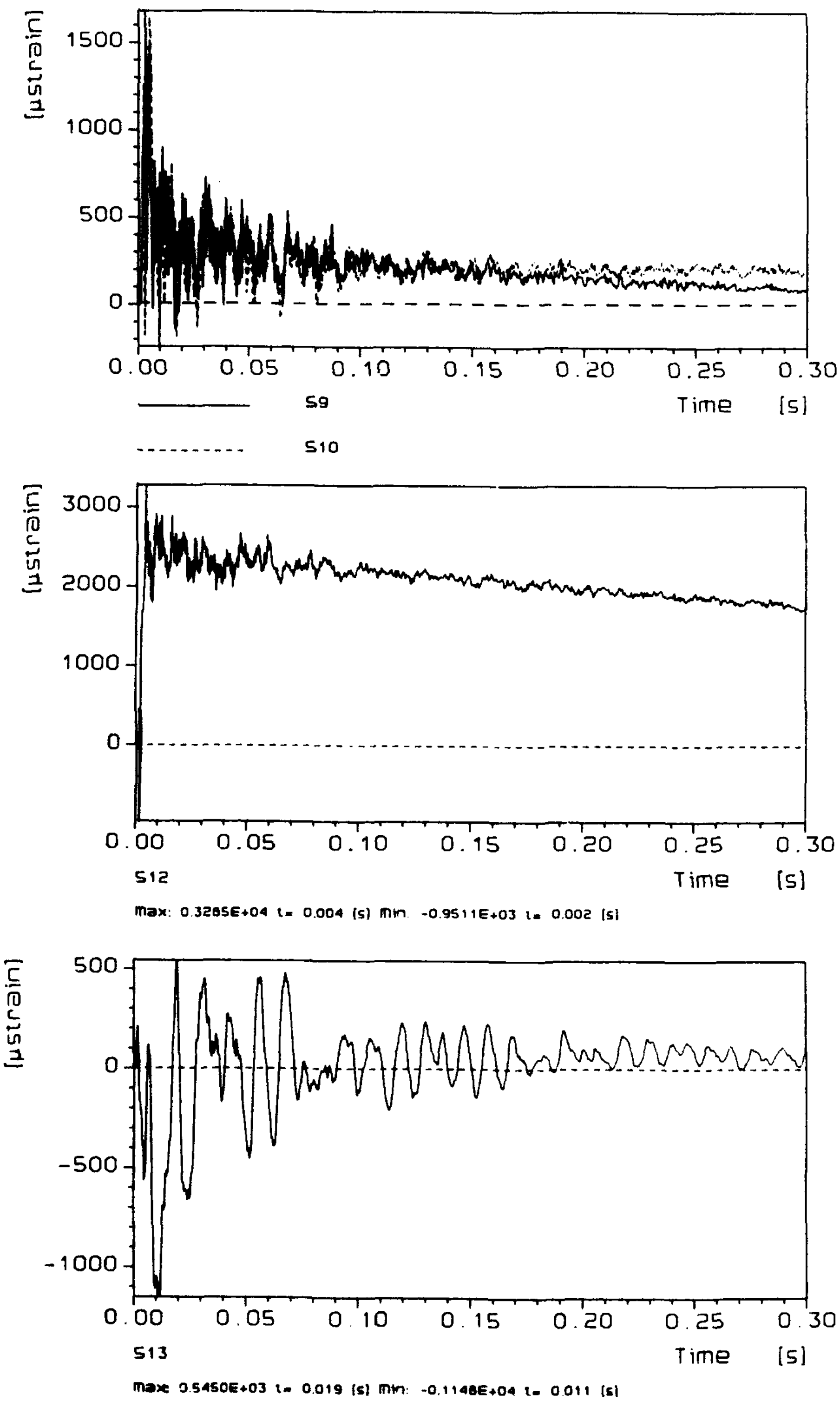


Figure 19 Strain gauge response S9 and S10, S12, S13 (BHD 71) (300 ms base)

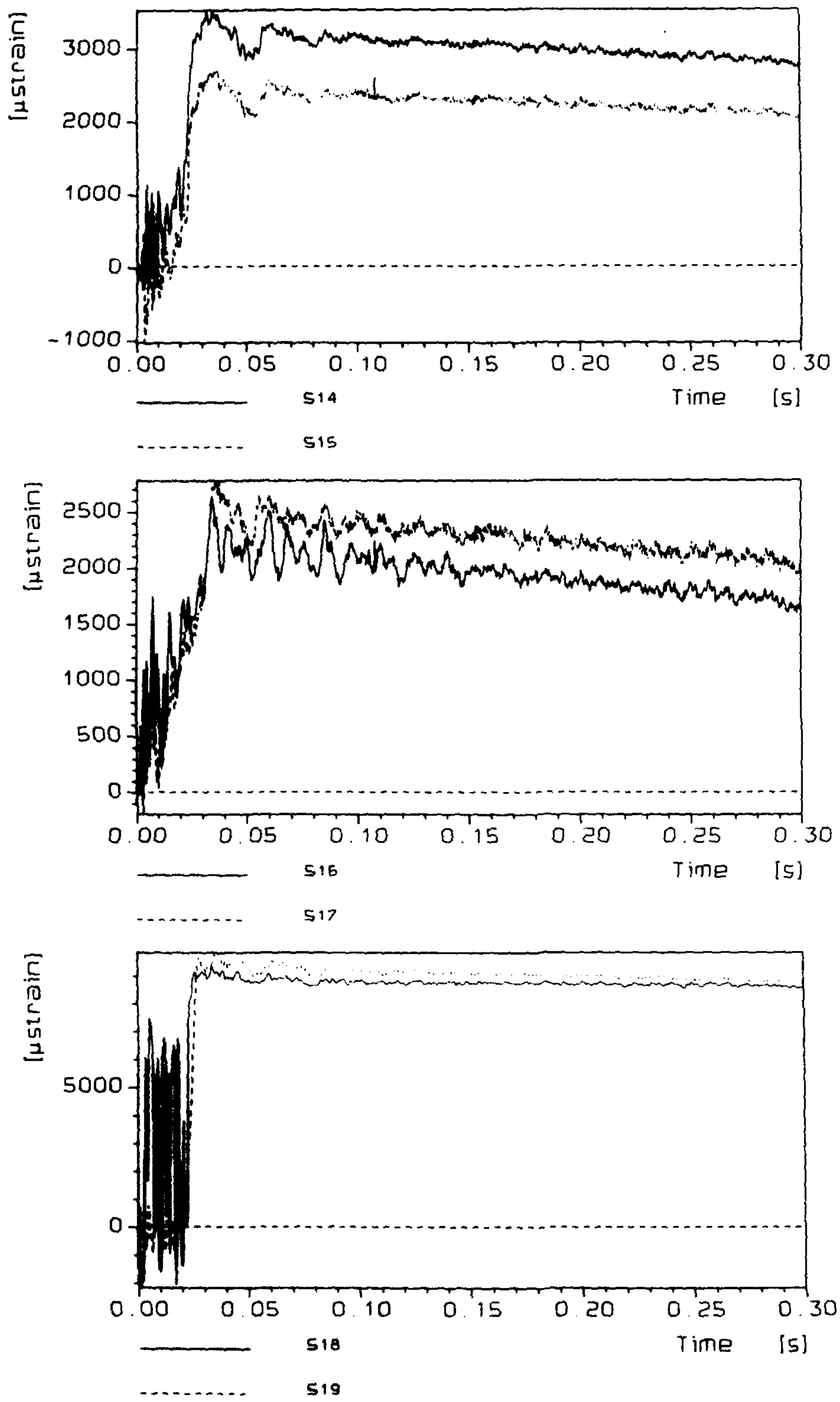


Figure 20 **Strain gauge response S14 and S15, S16 and S17, S18 and S19 (upper deck/ceiling) (300 ms base)**

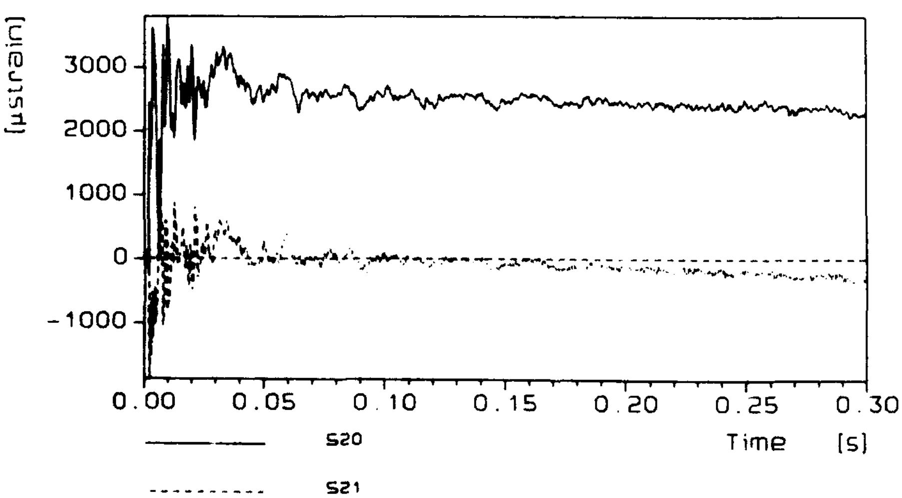


Figure 21 **Strain gauge response S20 and S21 (upper deck/ceiling) (300 ms base)**

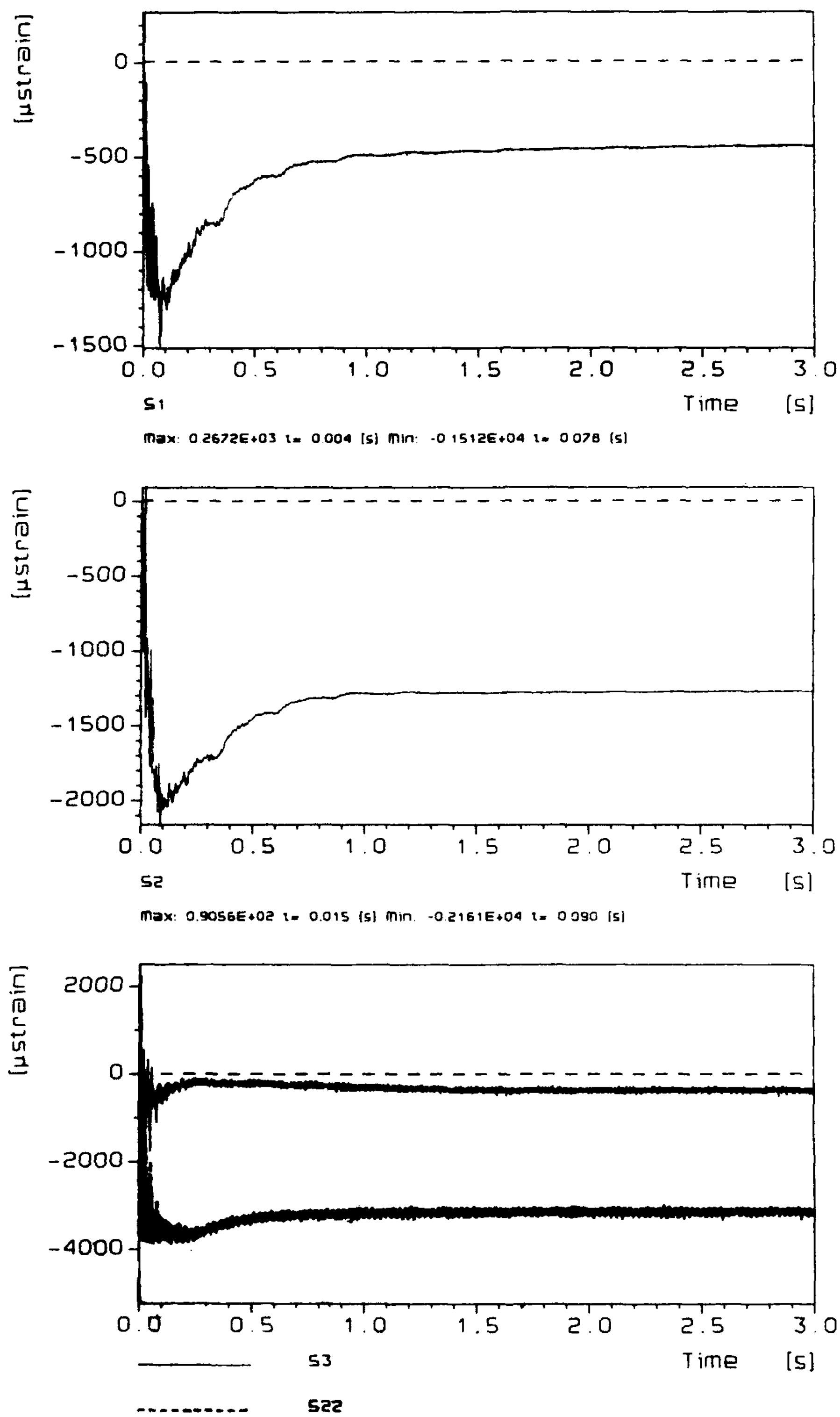


Figure 22 Strain gauge response S1, S2 (hull experiment compartment), S3 and S22 (BHD 71) (3 s base)

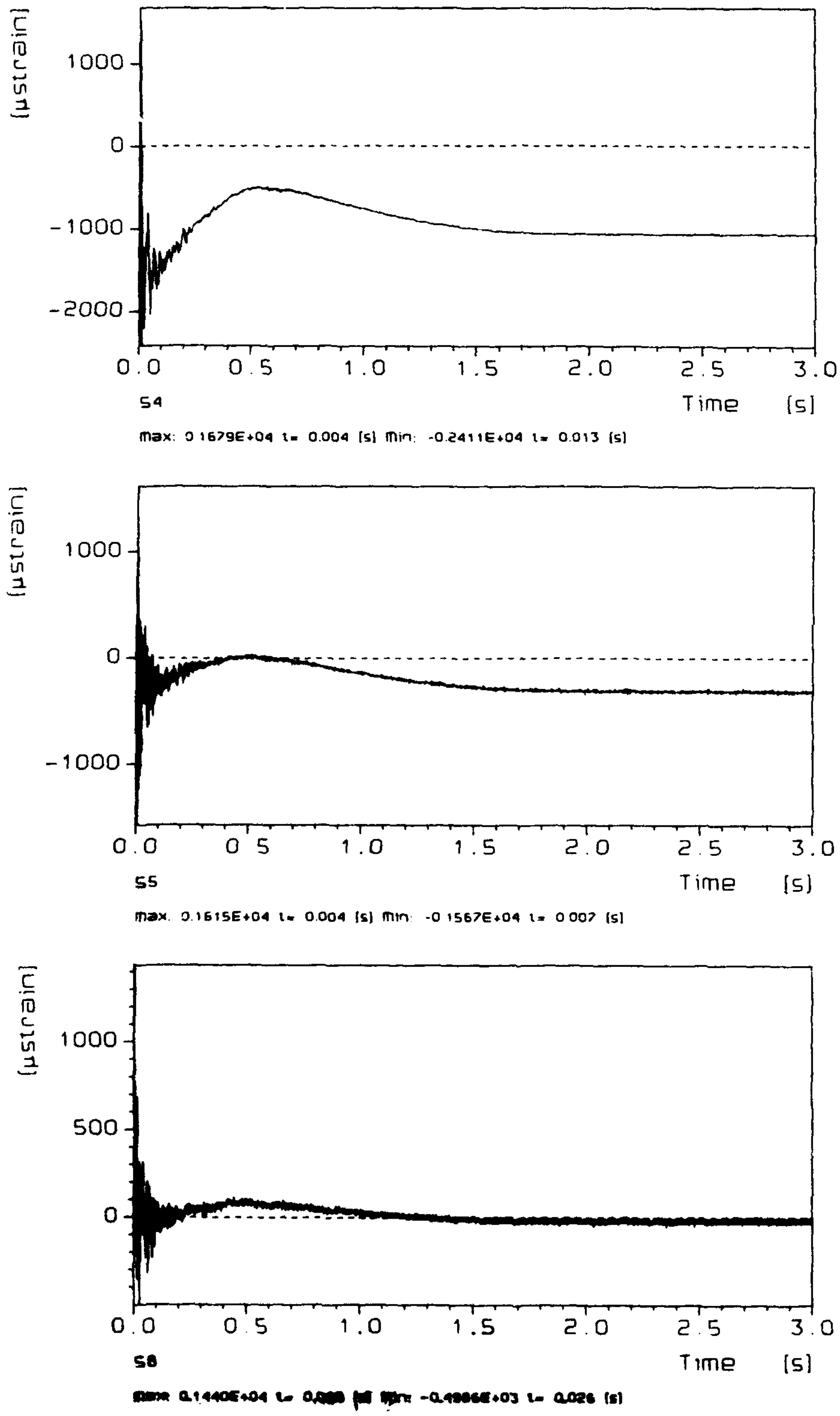


Figure 23 Strain gauge response S4, S5 and S6, S7 and S8 (BHD 71) (3 s base)

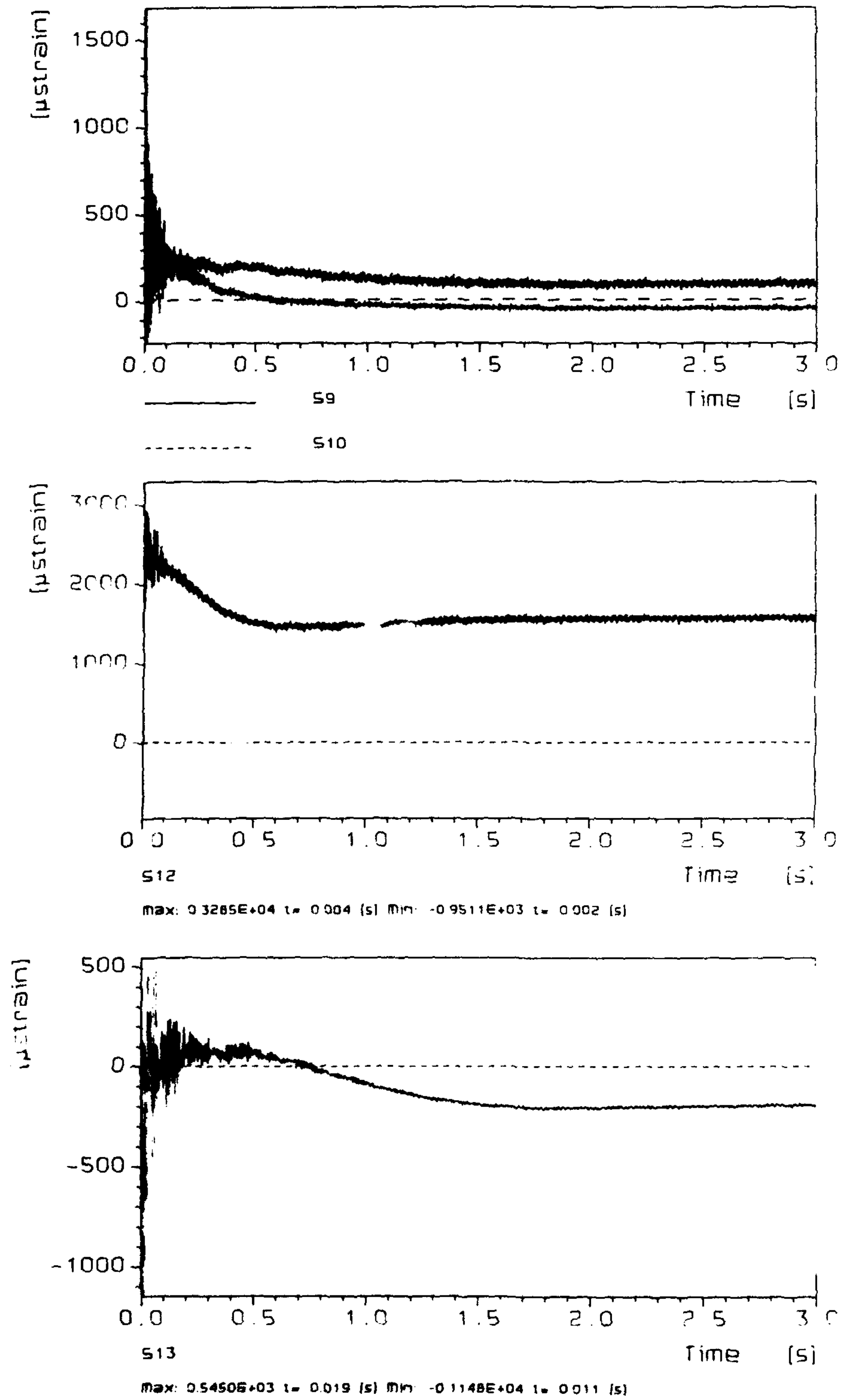


Figure 24 Strain gauge response S9 and S10, S12, S13 (BHD 71) (3 s base)

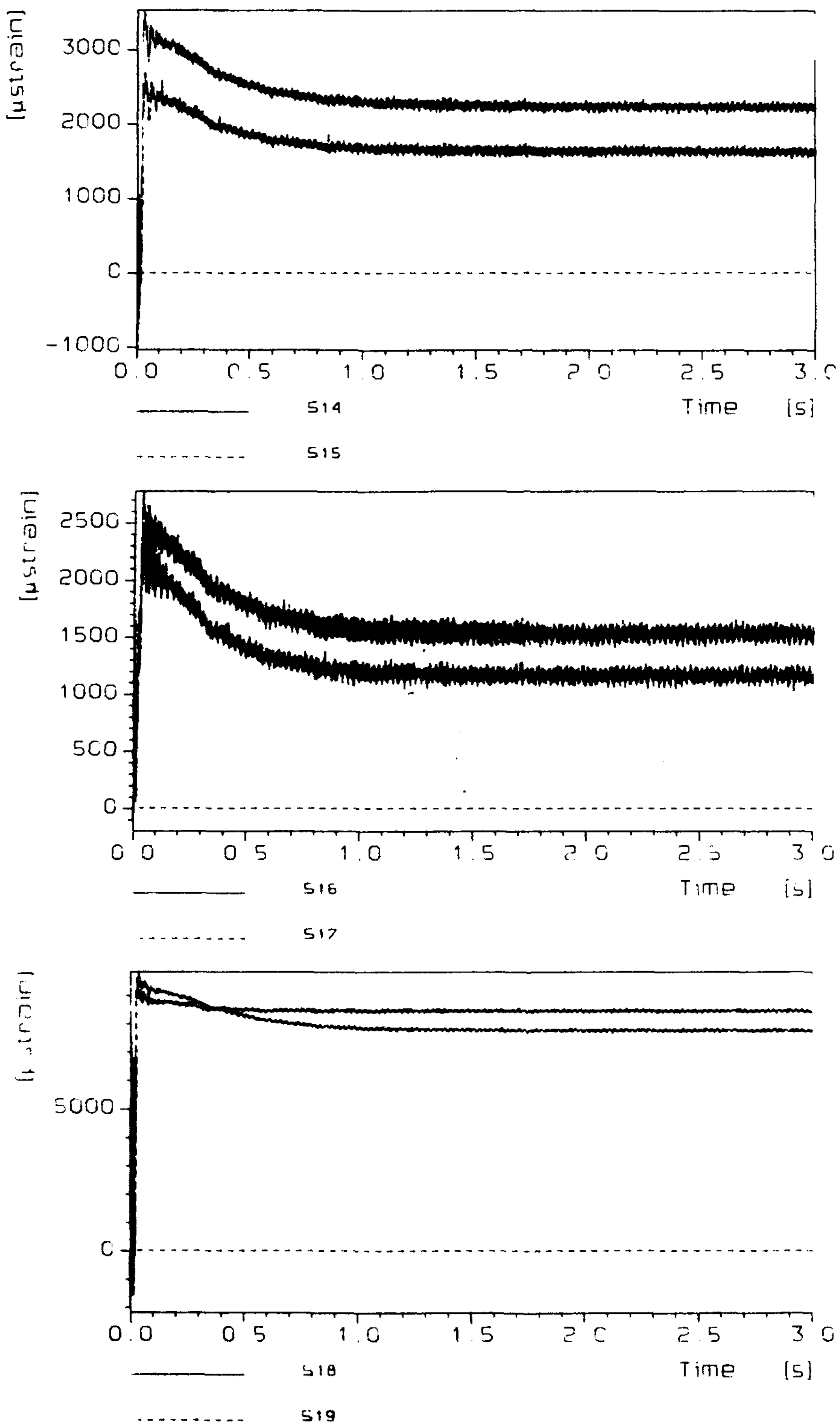


Figure 25 **Strain gauge response S14 and S15, S16 and S17, S18 and S19 (upper deck/ceiling) (3 s base)**

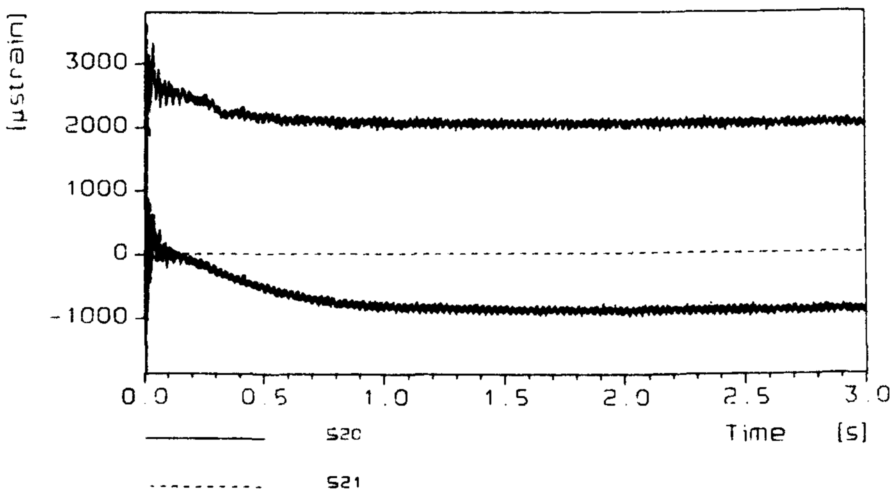


Figure 26 Strain gauge response S20 and S21 (upper deck/ceiling) (3 s base)

6 ACCELERATION MEASUREMENTS

6.1 Position of the accelerometers

During the experiments seven accelerometers were used, mounted on the H and J deck, respectively. The location of these accelerometers are summarized in Table 9 and shown schematically in Figures 27 and 28. In these figures the direction of sensitivity of the transducers is indicated by the length axis of the ■ blocks.

Table 9 Position of the accelerometers

Device	Mounting position		
A1(1)			108 cm beneath ceiling J-deck on CL stiffener
A2	ceiling	J-deck	281 cm from BHD 78, 146 cm SB from CL
A3	floor	J-deck	281 cm from BHD 78, 146 cm SB from CL
A4	ceiling	J-deck	263 cm from BHD 71, on SB girder
A5	ceiling	J-deck	74 cm from BHD 45, on PS girder
A6	floor	J-deck	75 cm from BHD 45
A7(1)			111 cm above floor J-deck on stiffener

(1) vertical direction

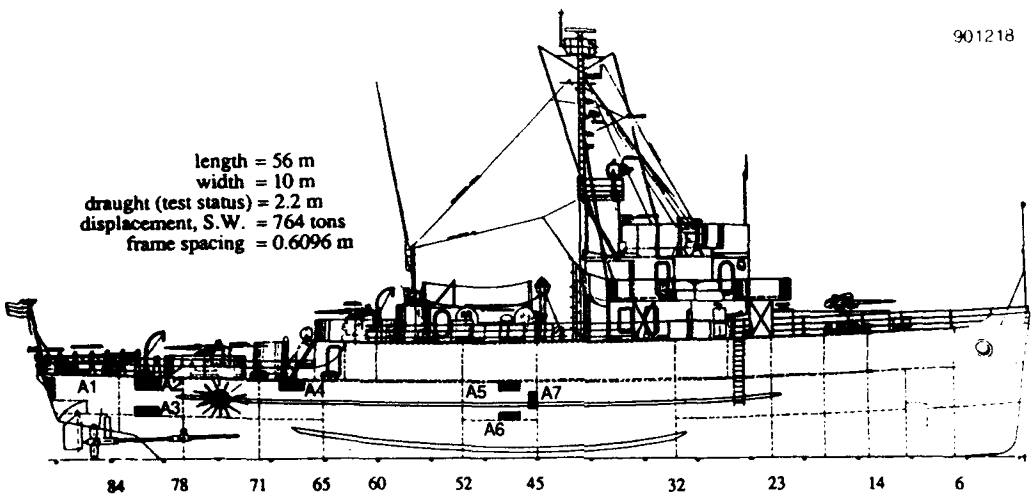


Figure 27 Schematic illustration of the positions of the accelerometers

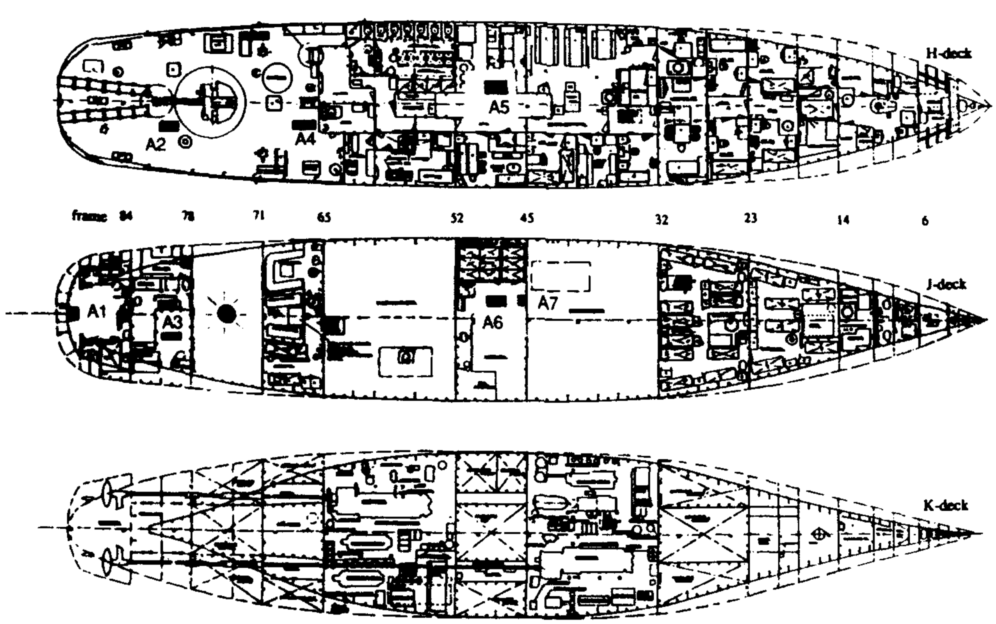


Figure 28 Schematic illustration of the positions of the accelerometers

6.2 Discussion of the acceleration measurements

The results of the acceleration measurements are shown in Figures 29-35. A distortion of 50 Hz was removed from the signals to enable the determination of the velocity and the displacement by integrating the signals with respect to the time. In addititon, drift correction was necessary to suppress the influence of baseline shifts. A third order low pass Butterworth filter (1.5 kHz) was used to suppress the high frequency components of the original acceleration signals. The acceleration signals, as well as the velocity and some of the displacement signals, seem to be of good quality. However, some of the displacement signals still show a drift. It is obvious that these (rather ad hoc) signal analysis techniques strongly influence the presented velocity and displacement signals. The time-scale used in the figures is adapted to the individual signal response.

Additionally, the shock spectra are presented in Figures 36-42. The positive and negative residual shock spectra are identical because damping was omitted.

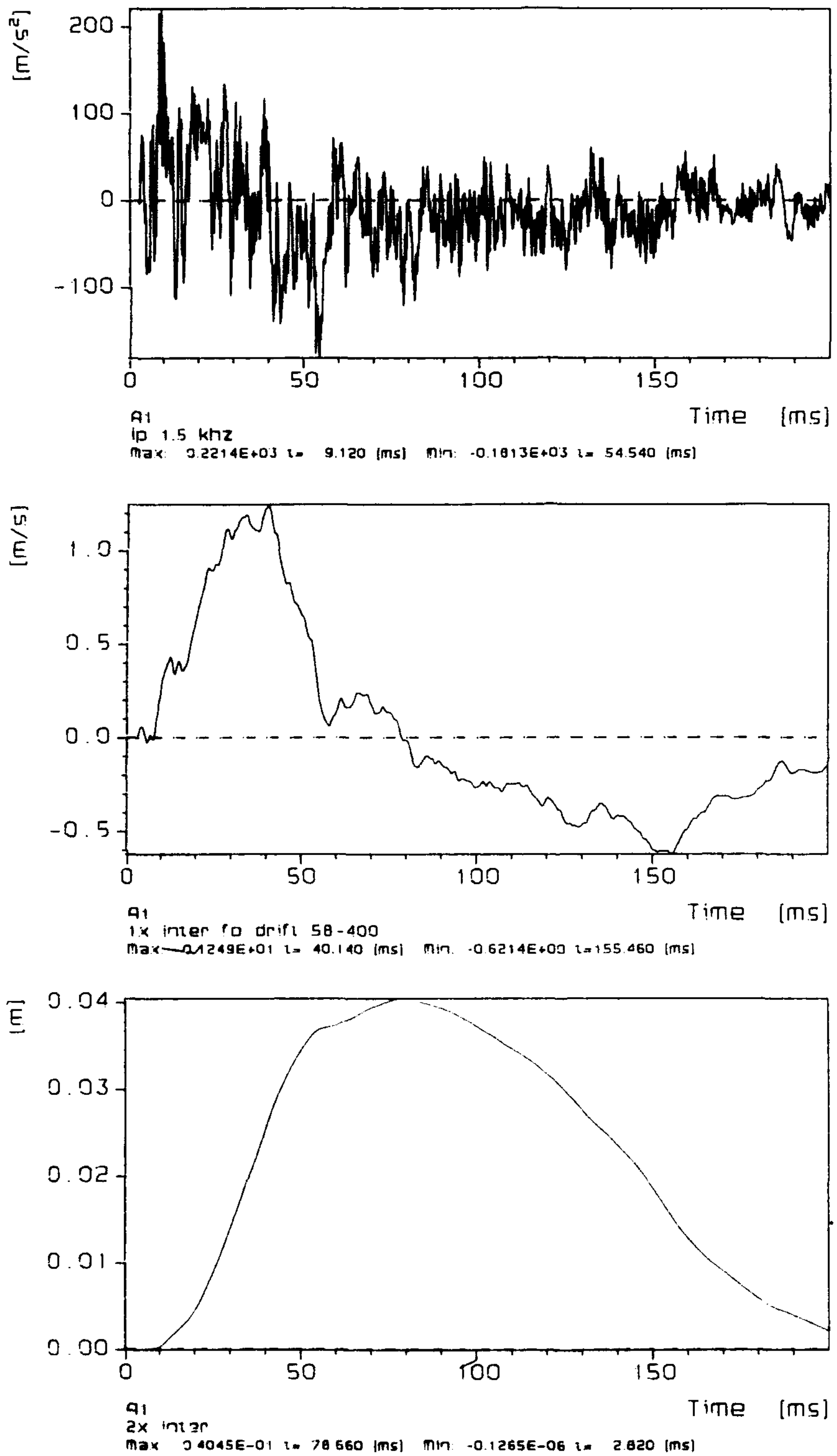


Figure 29 Accelerometer A1

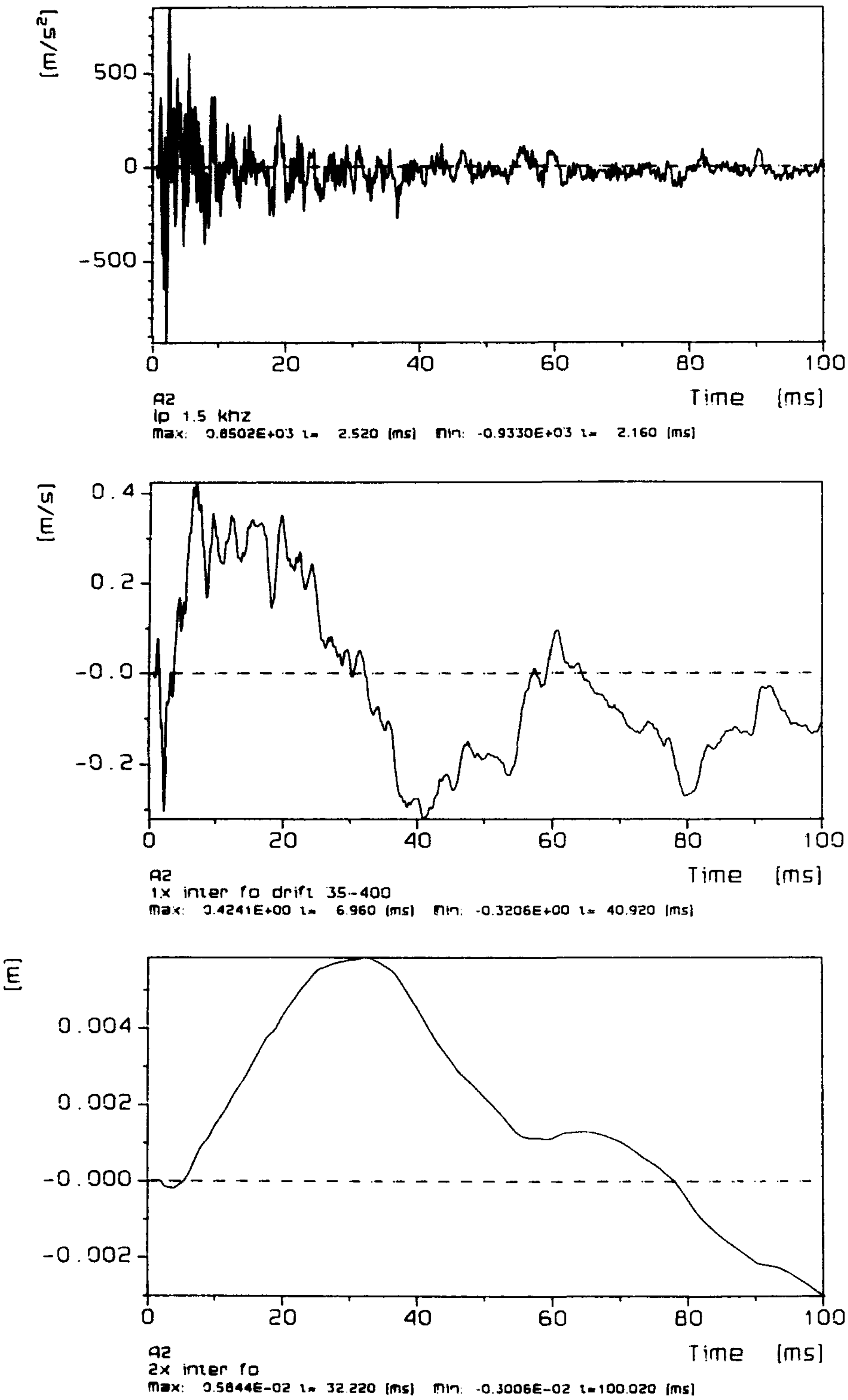


Figure 30 Accelerometer A2

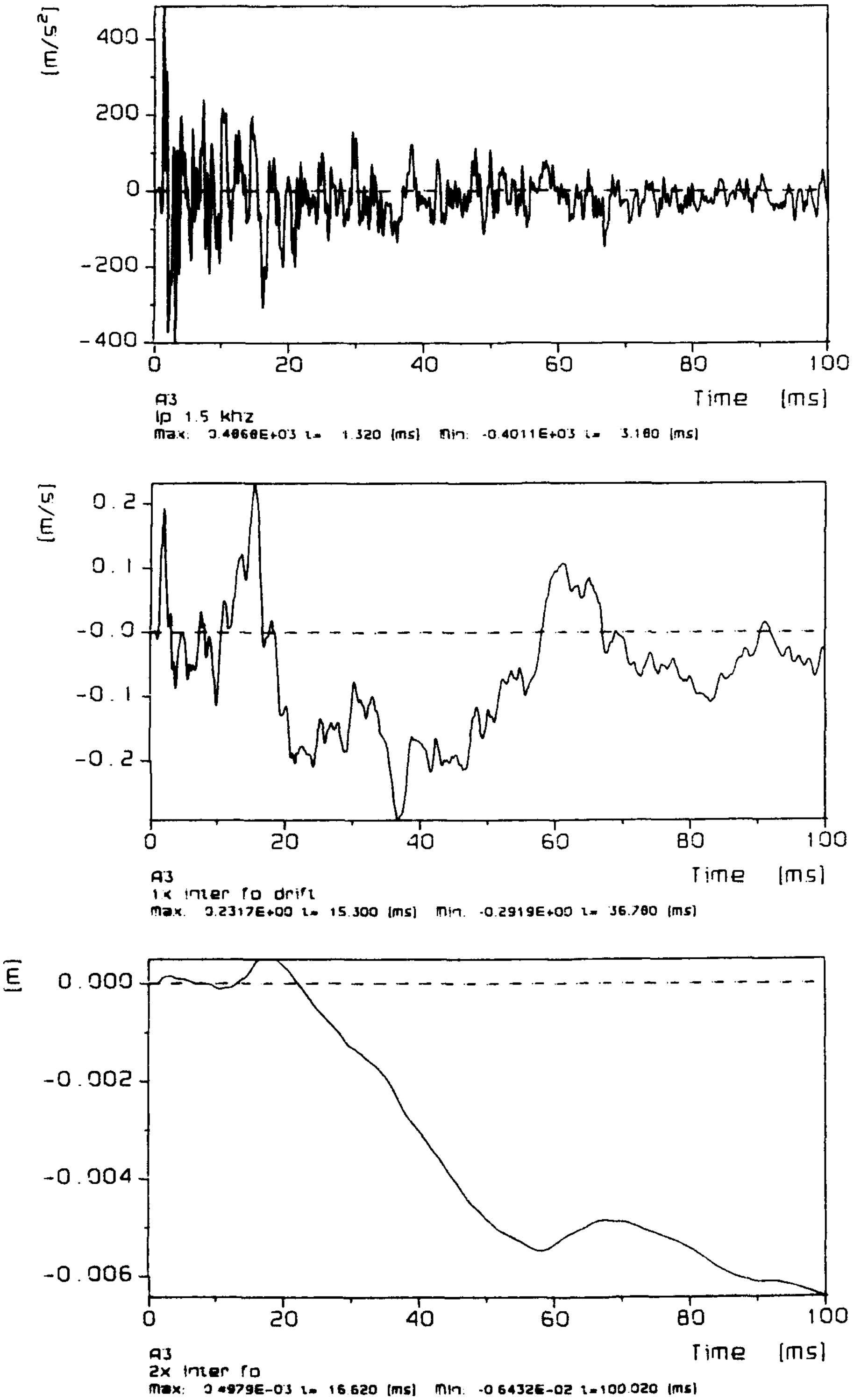


Figure 31 Accelerometer A3

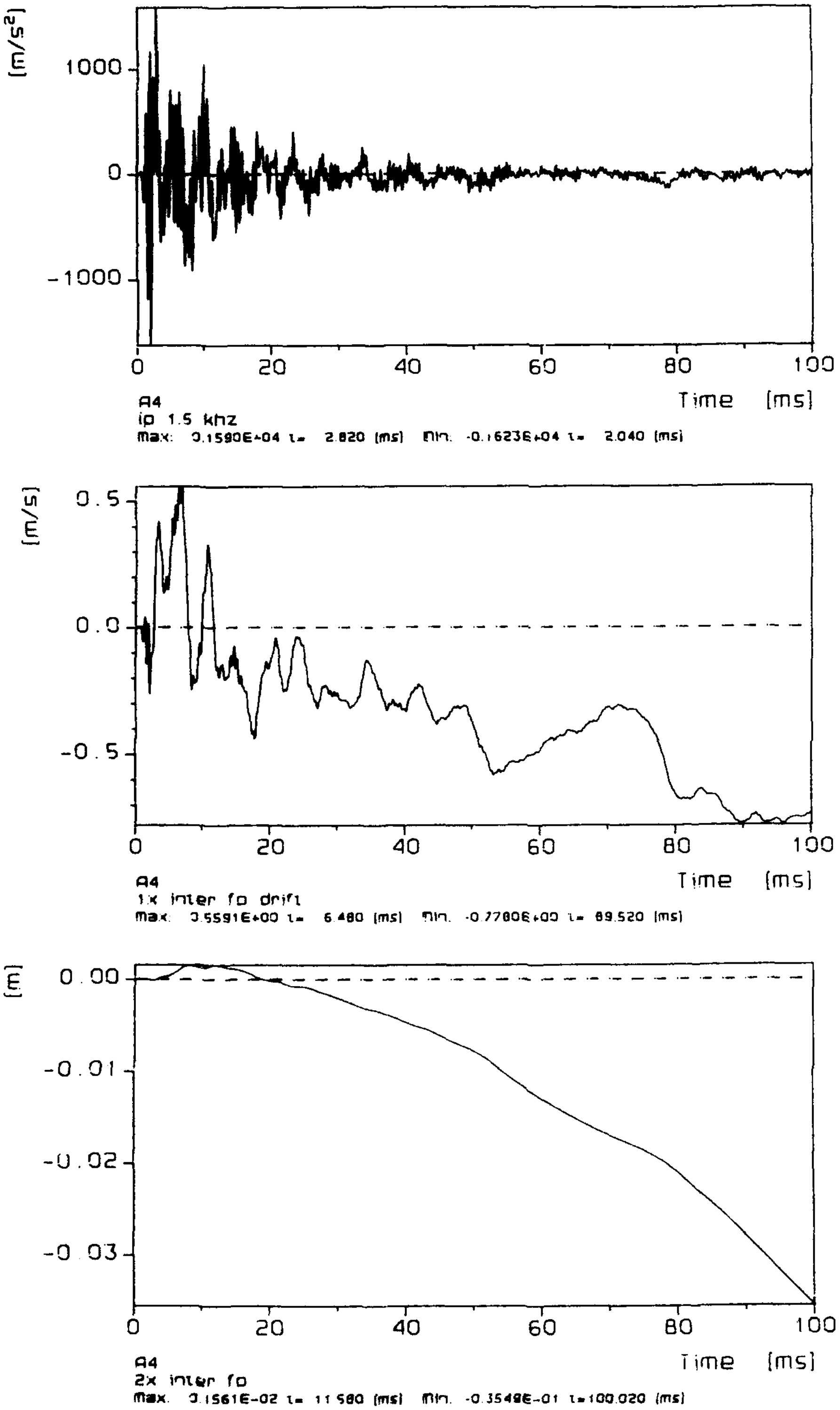
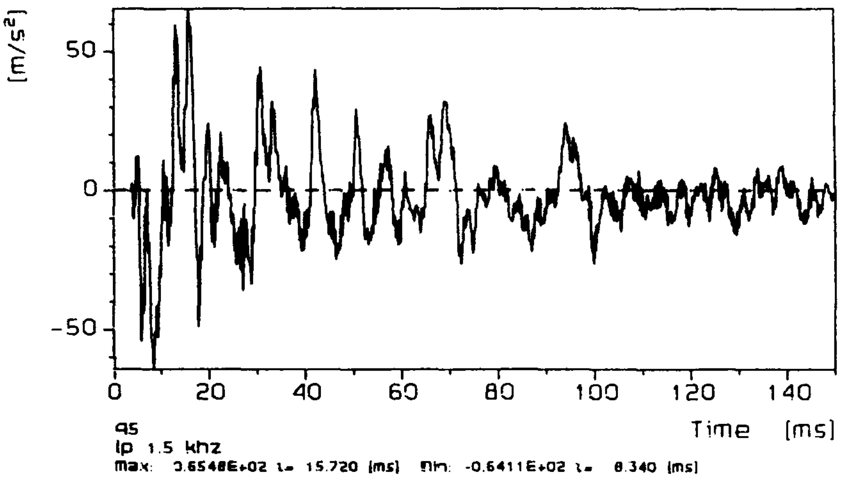
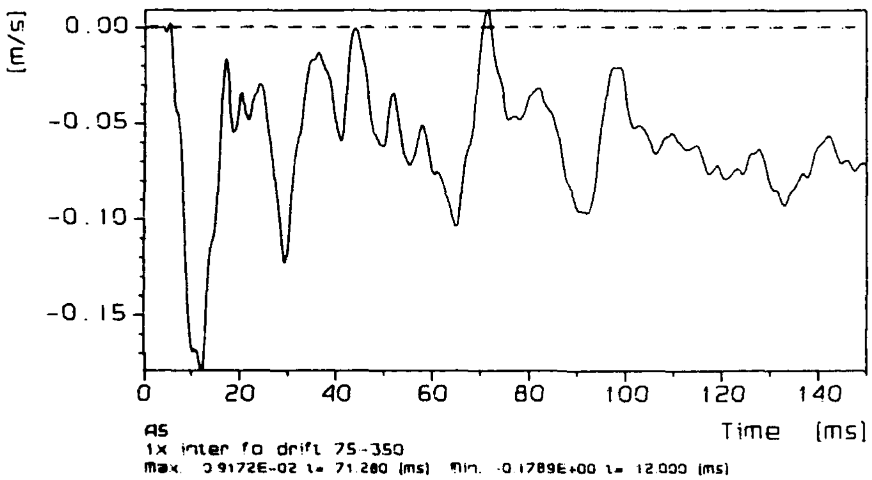


Figure 32 Accelerometer A4





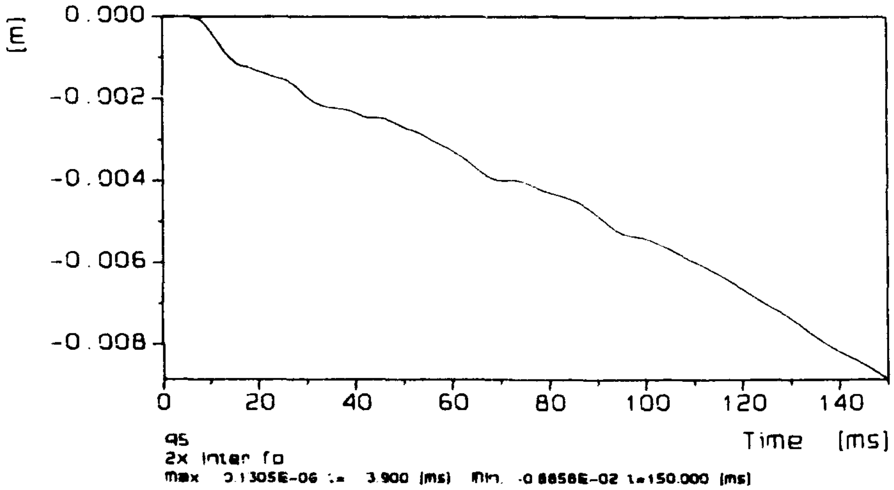


Figure 33 **Accelerometer A5**

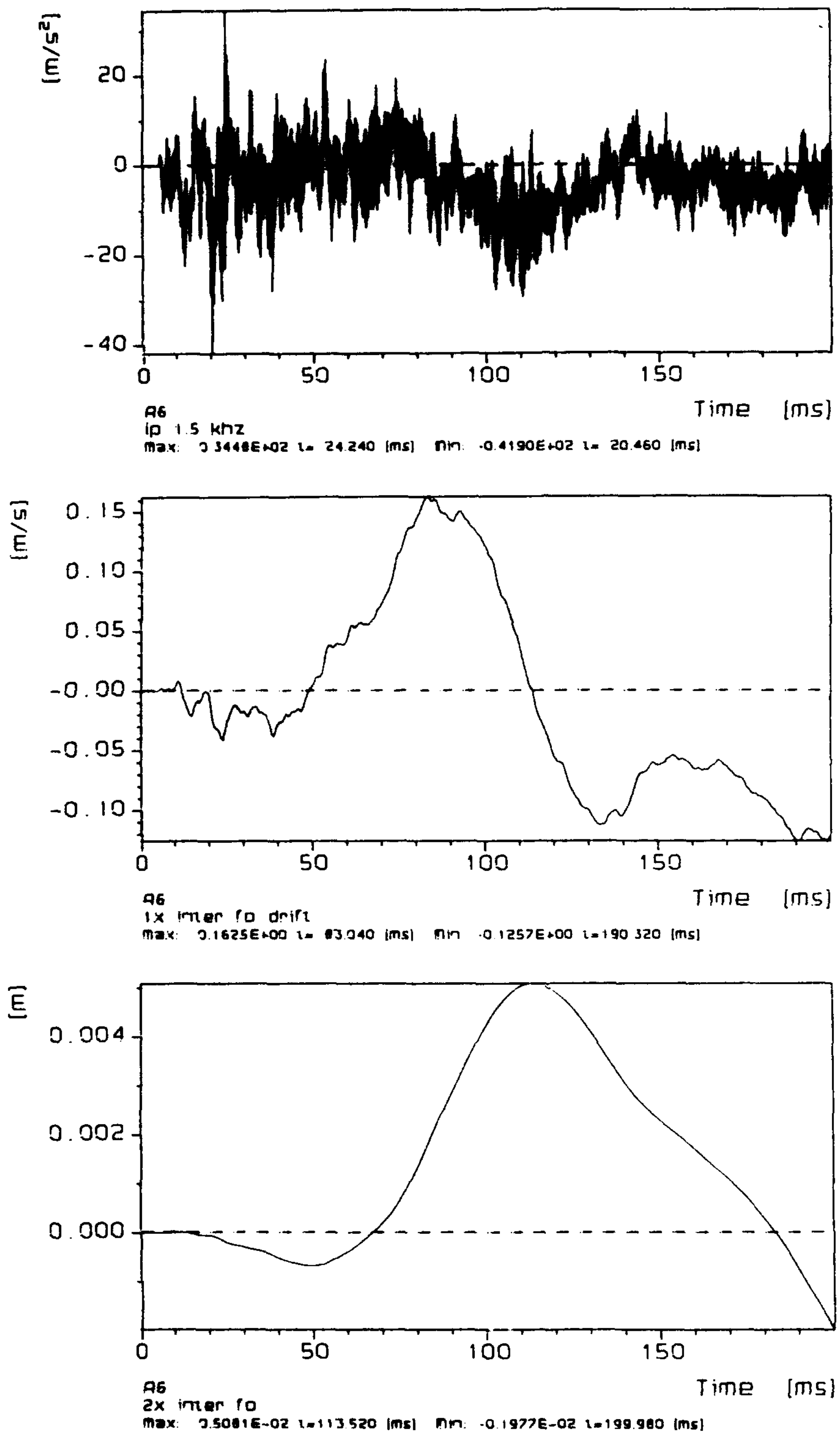


Figure 34 Accelerometer A6

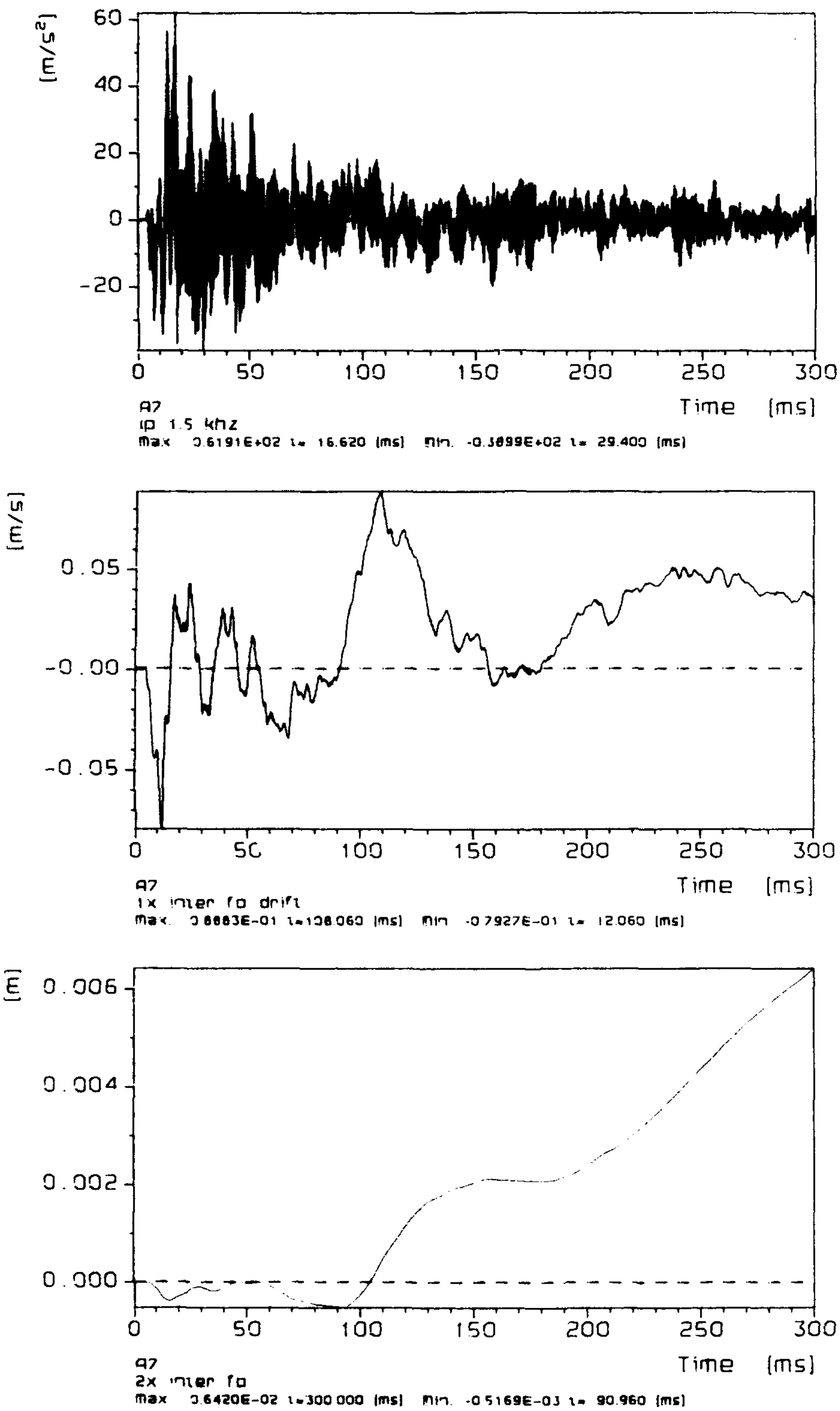
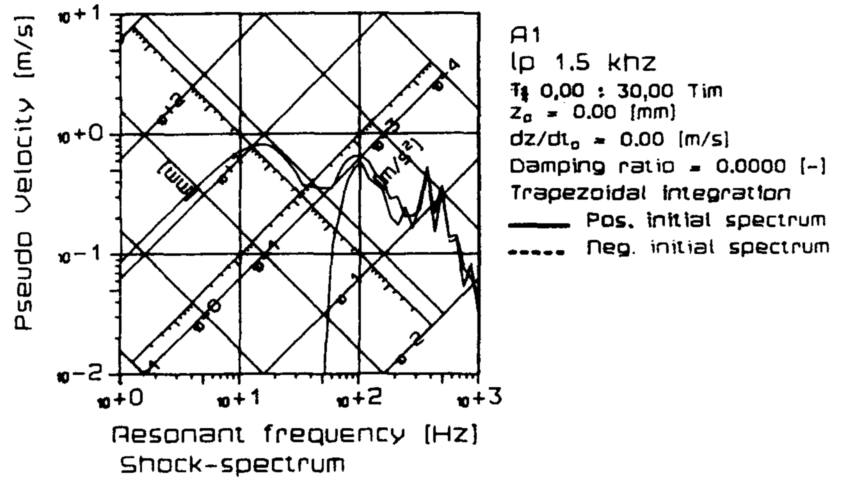
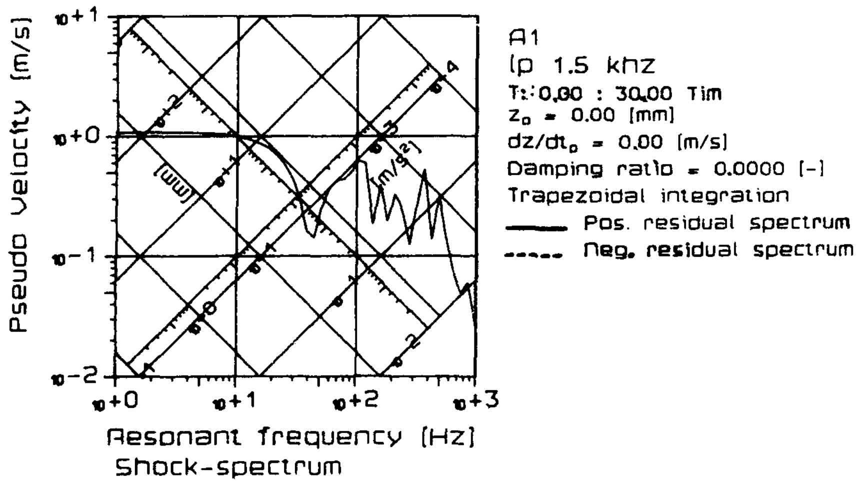


Figure 35 Accelerometer A7





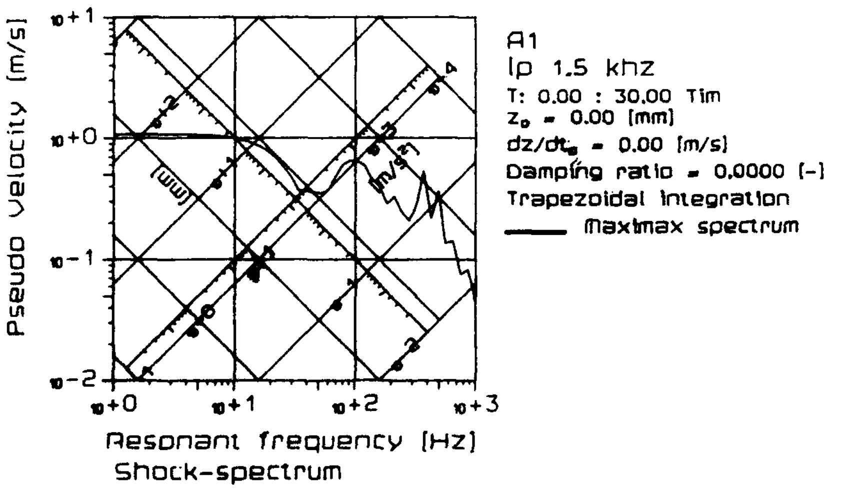
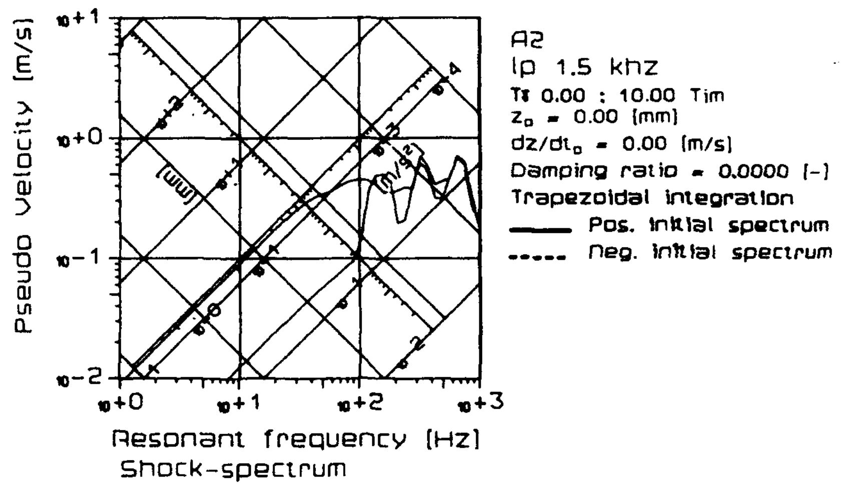
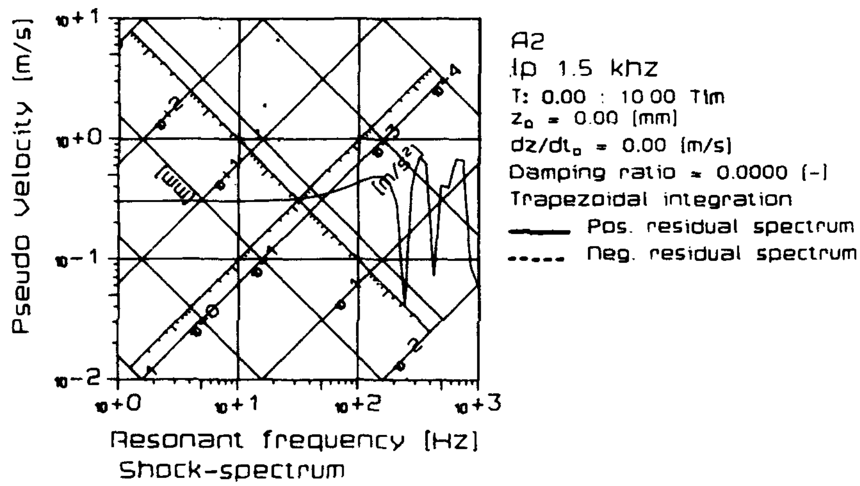


Figure 36 Shock spectra accelerometer A1





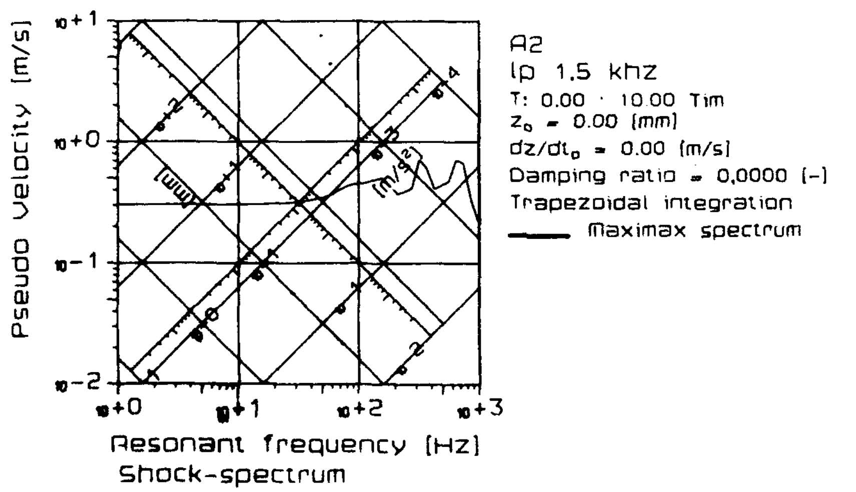
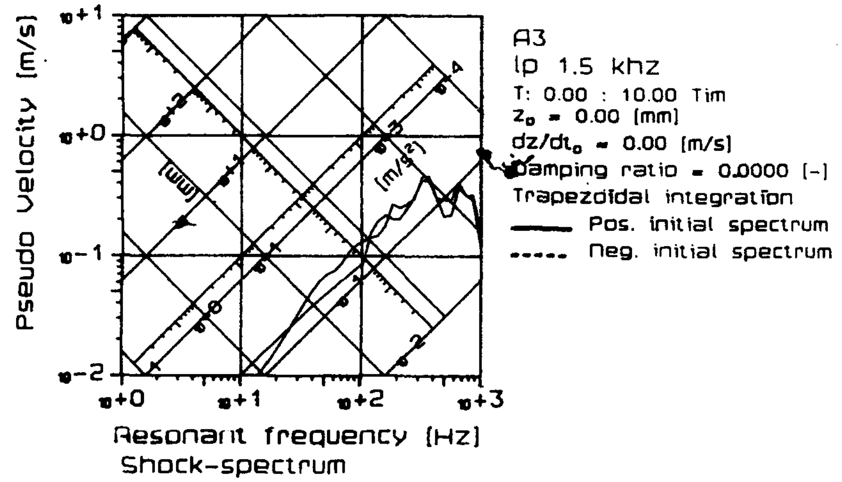
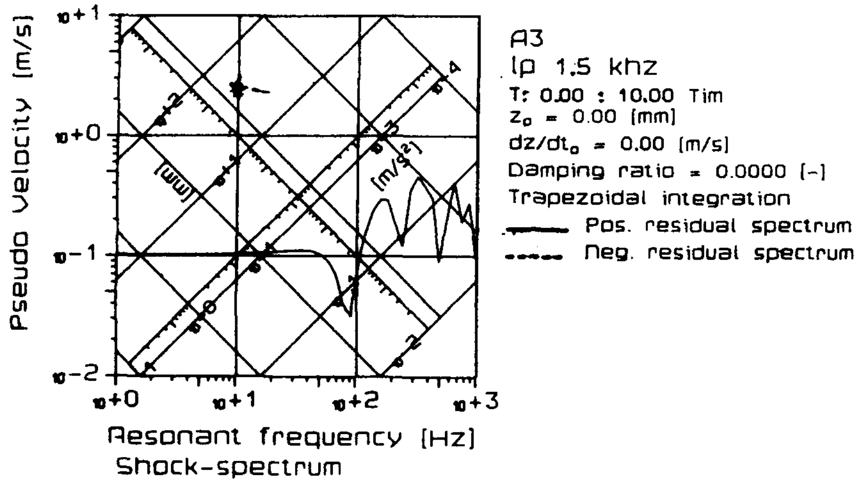


Figure 37 **Shock spectra accelerometer A2**





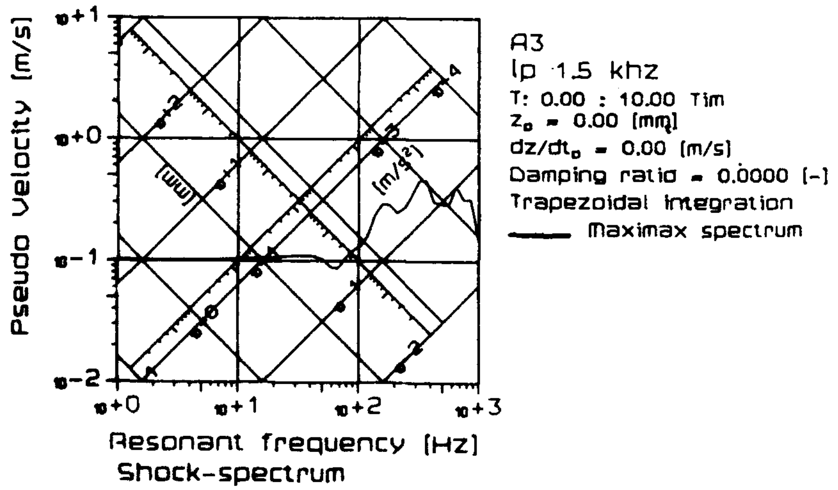
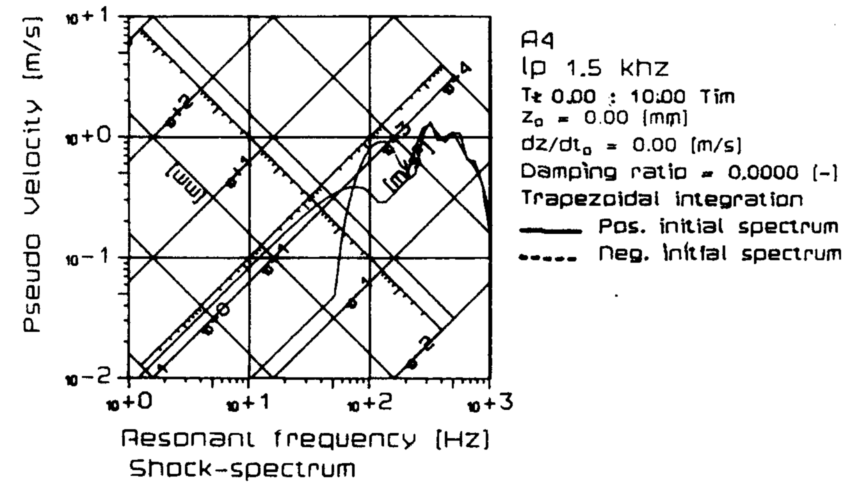
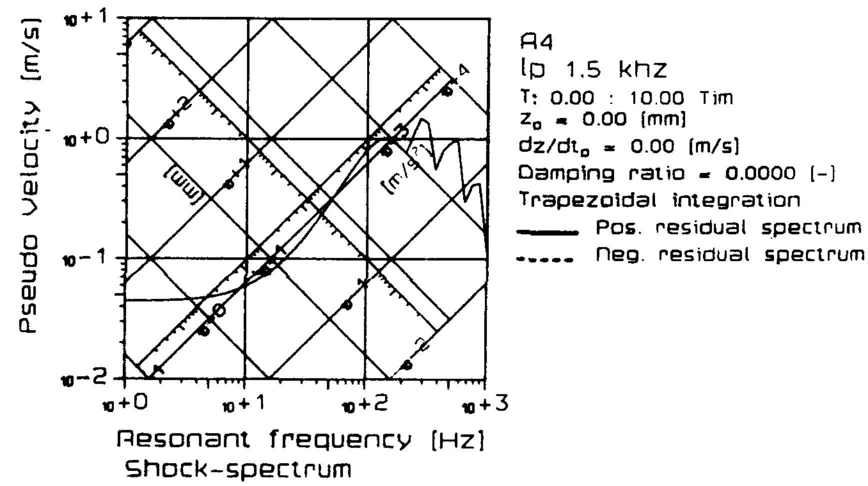


Figure 38 Shock spectra accelerometer A3





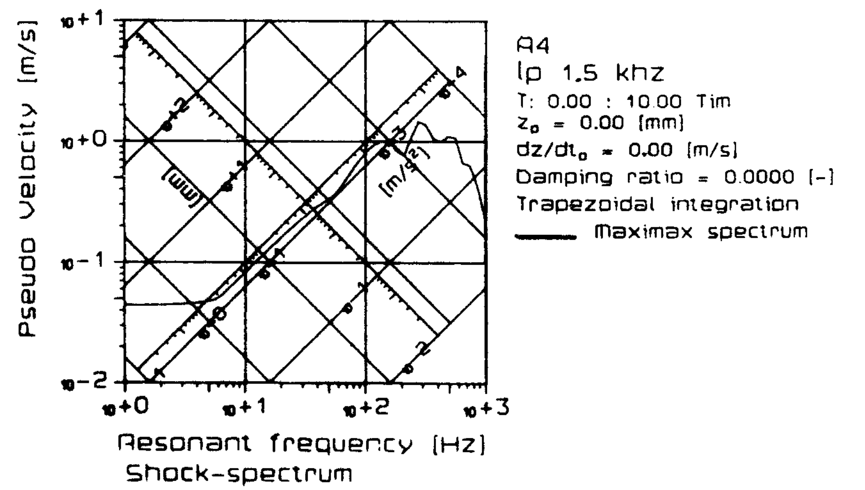


Figure 39 Shock spectra accelerometer A4

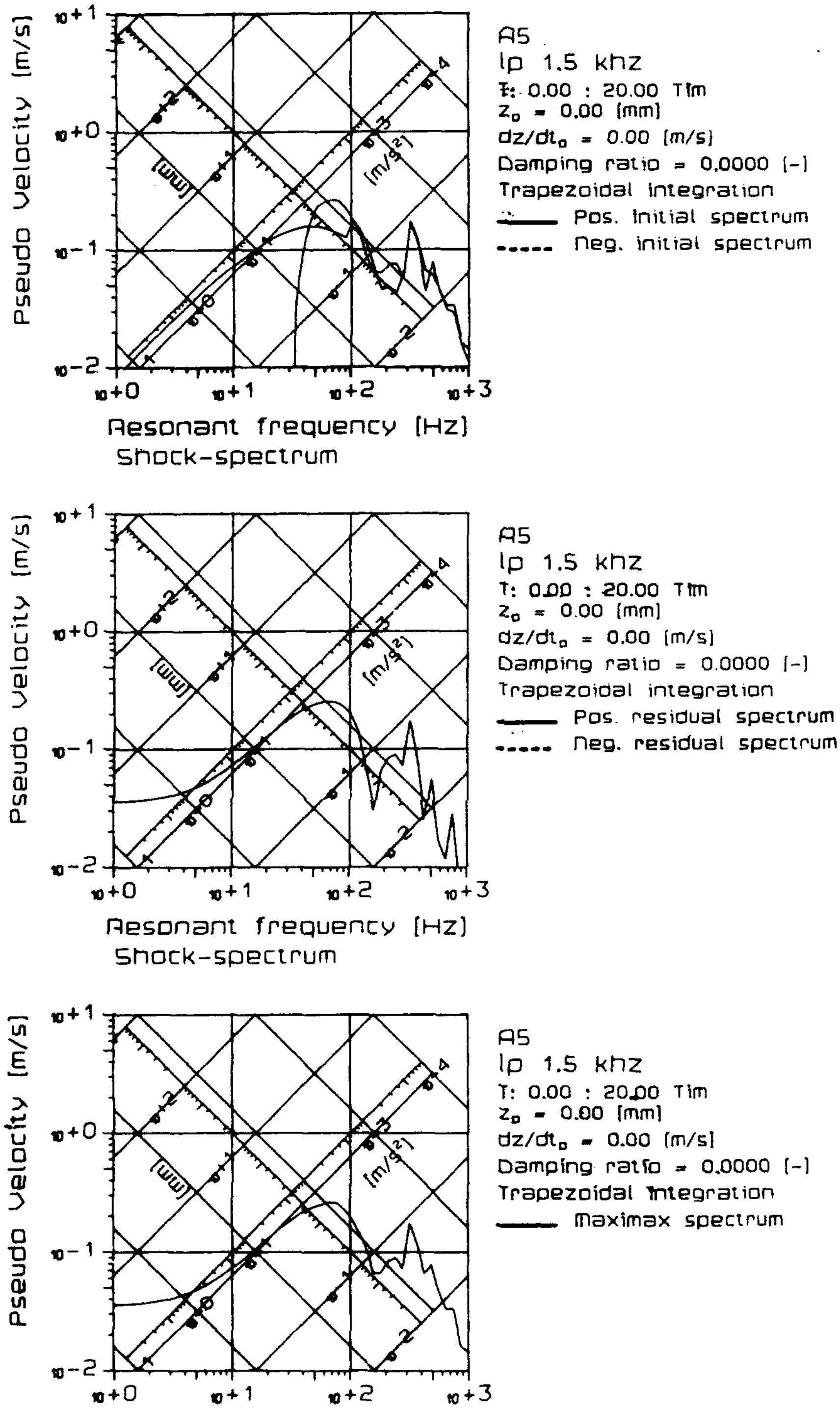
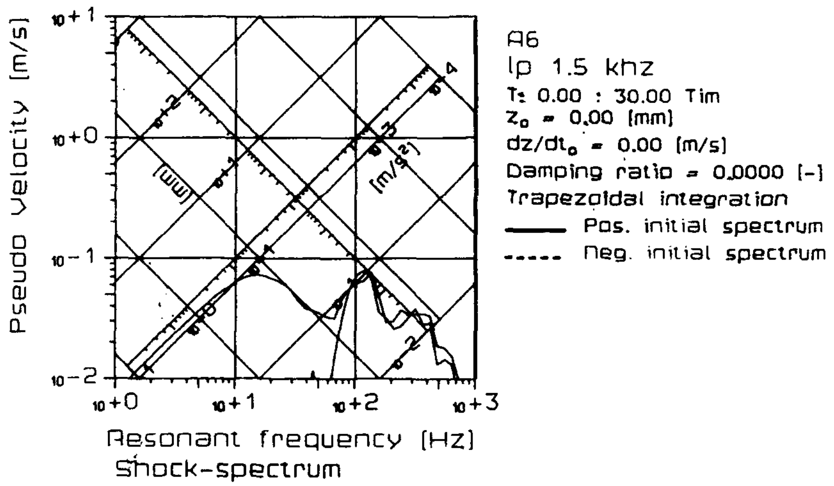
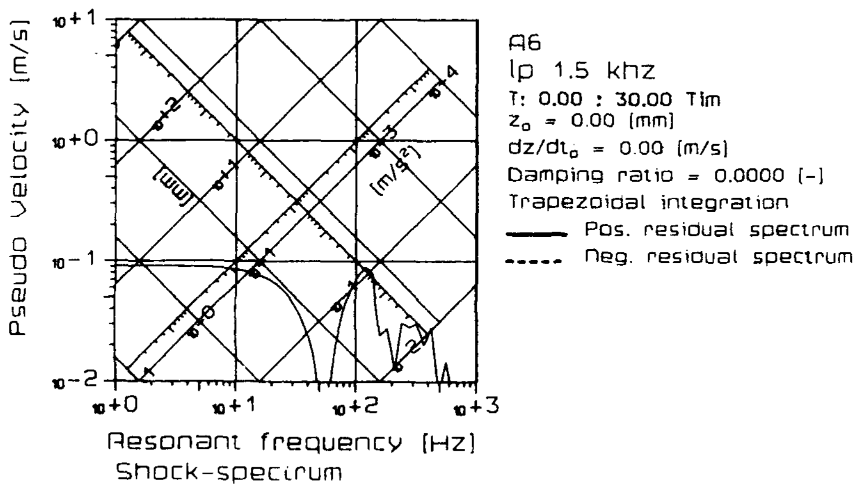


Figure 40 Shock spectra accelerometer A5





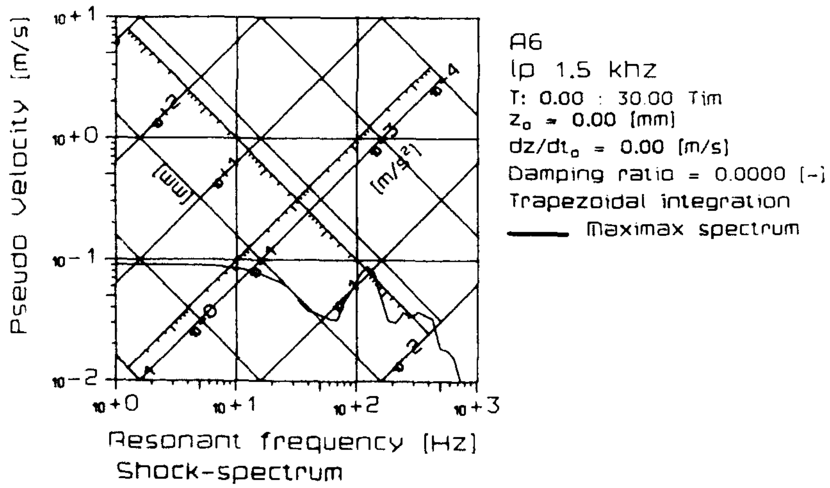


Figure 41 Shock spectra accelerometer A6

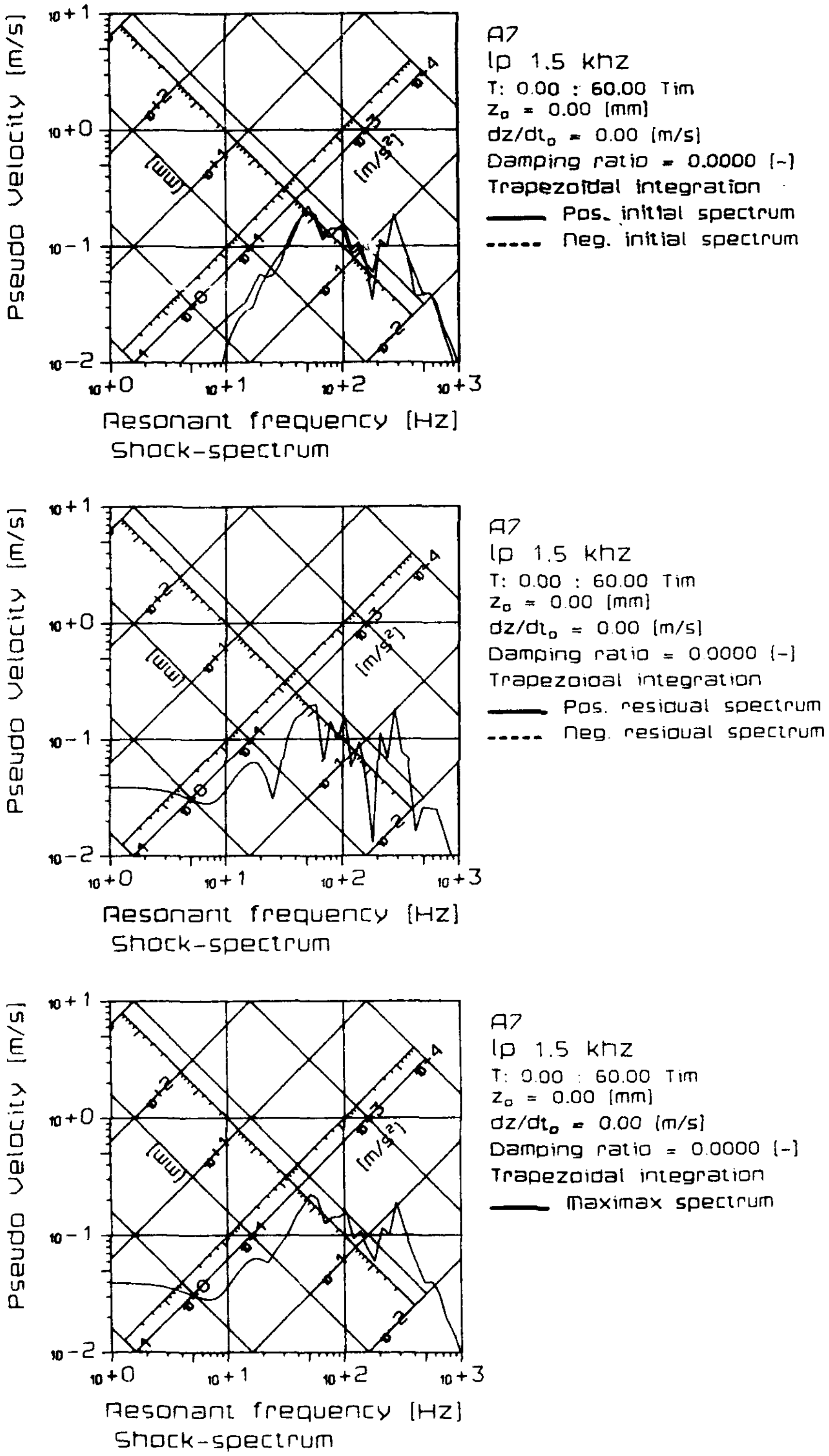


Figure 42 Shock spectra accelerometer A7

7 TEMPERATURE MEASUREMENTS

7.1 Position of the temperature transducers

During the experiment, the temperature was measured in three places. The location of the temperature measurements are summarized in Table 10 and shown schematically in Figure 42.

Table 10 Position of the temperature transducers

Device	Height	Position
T1(1,*)	125 cm	beside Q1, SB, in experiment compartment
T2	118 cm	beside Q3, corporals' sleeping compartment
T3	149 cm	115 cm from CL, munition depository

(1) near venting hole
(*) malfunctioned during the 2 kg TNT experiment

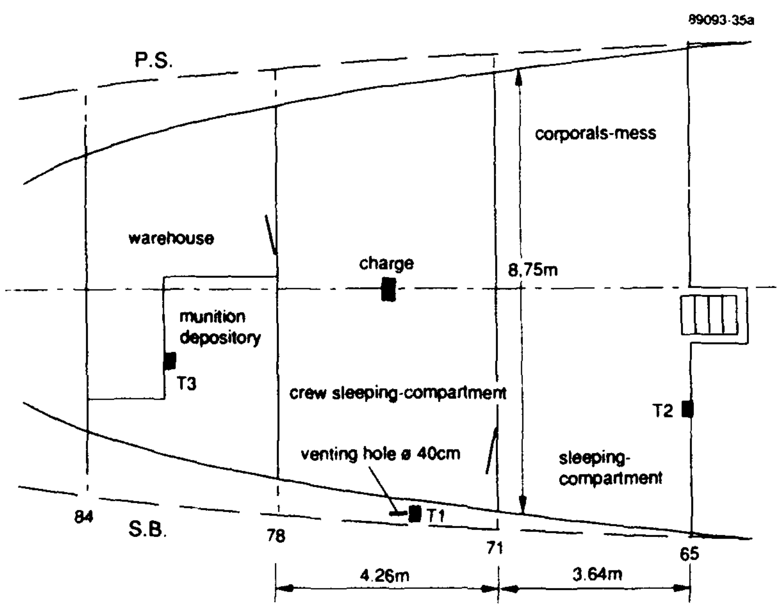


Figure 43 Schematic illustration of the positions of the temperature transducers

7.2 Discussion of the temperature measurements

In Figure 44, the recorded temperatures are shown. Note that, in fact, a temperature increment dT is shown and not an absolute temperature, i.e. T=0 corresponds with the ambient temperature. No problems arose from device T1 during this experiment although this device malfunctioned after 1 s during the previous 2 kg TNT experiment.

Note also that the quasi-static pressure recorded in the munition depository exceeded the recordings in the corporals' sleeping compartment. The temperature recordings in these compartments were similar.

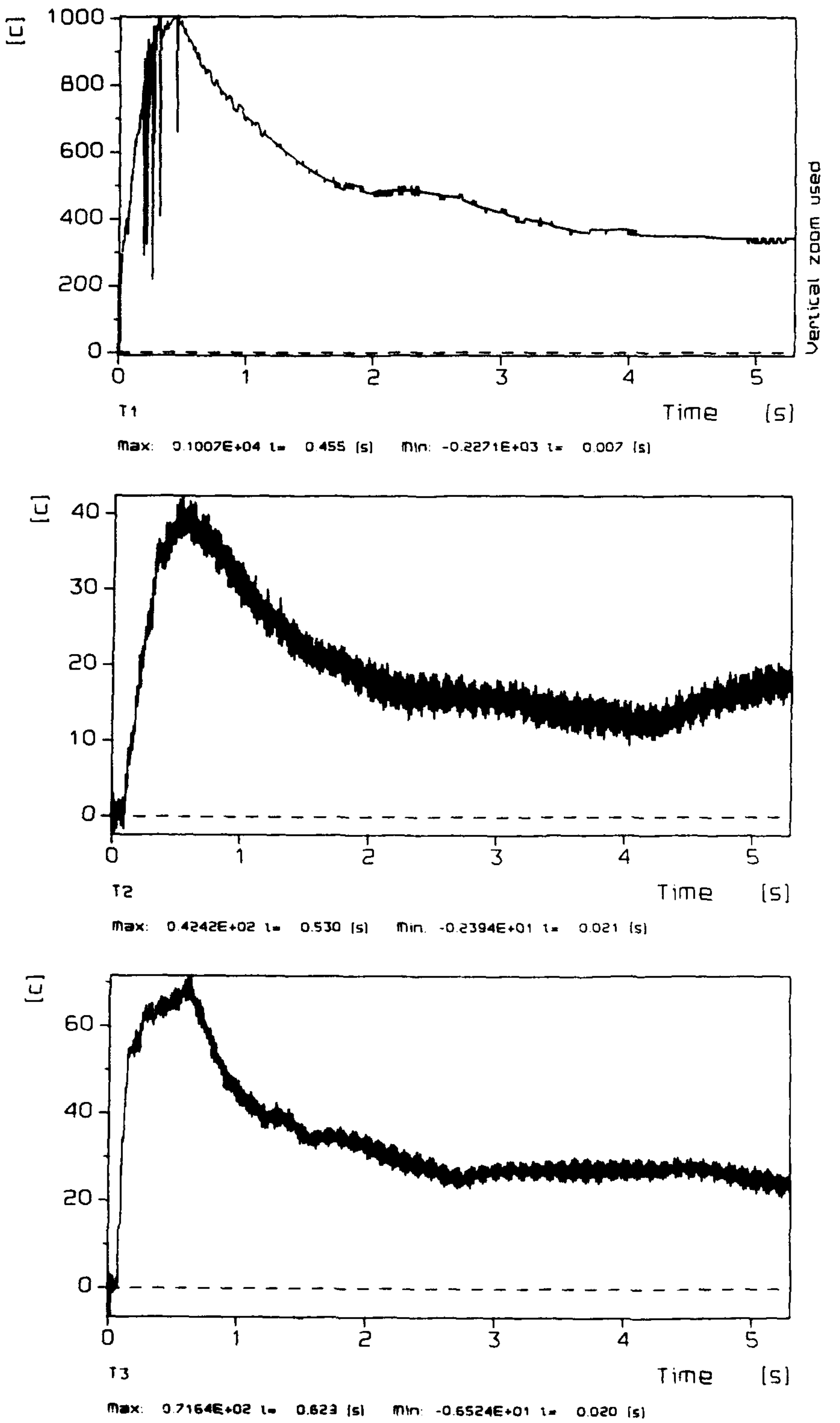


Figure 44 The temperature increments

8 BREAKWIRES

8.1 Position of the breakwires

In order to determine the possible moment of collapse of the watertight doors, breakwires were used. The positions are summarized in Table 11 and are shown schematically in Figures 45 and 46.

Table 11 Position of the breakwires

Device	Height(1)	Position
BW1	112 cm	back side of the door in BHD 71
BW2	27 cm	back side of the door in BHD 71
BW3	81 cm	back side of the door in BHD 78

(1) Height with respect to the lower side of the door

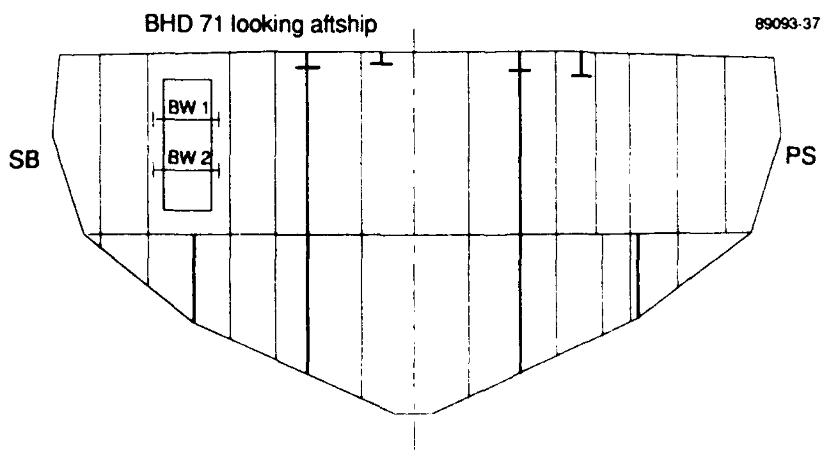


Figure 45 Schematic illustration of the position of the breakwire in BHD 71

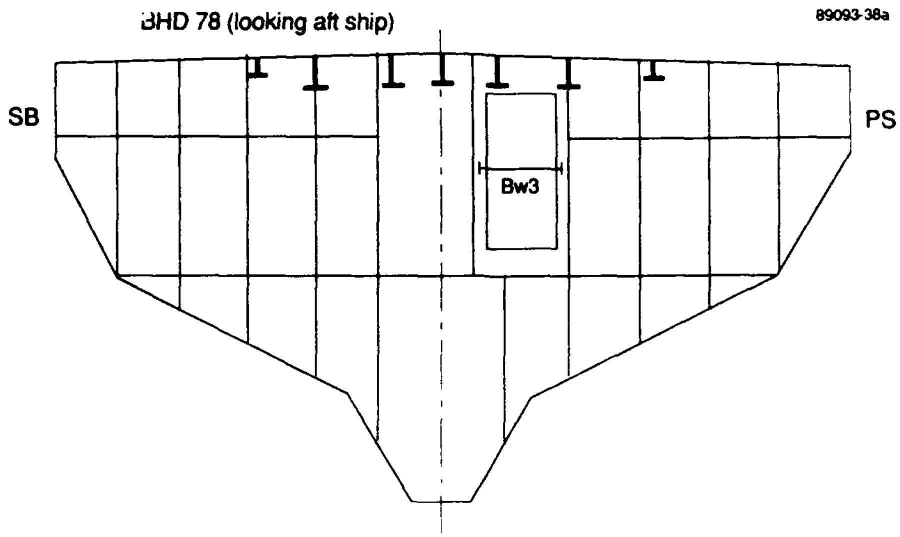


Figure 46 Schematic illustration of the position of the breakwire in BHD 78

8.2 Discussion of the breakwire measurement

The recorded signals are shown in Figure 47. Note that the shock front will reach device B3 first before arriving at the door in BHD 78. The start of the BW3 signal (1.5 ms) must therefore be a little later than the arrival time of the shock front at B3 (1.2 ms). From BW1 and BW2 it appears that the arrival time of the shock front at the door in BHD 71 will be about 1.4 ms. This time is in between the arrival time of the shock front at B4 (1.1 ms) and B5 (1.9 ms). It must be noted that the doors did not collapse. Therefore the recorded signals must be due to the vibration of the microswitches used in combination with the breakwires.

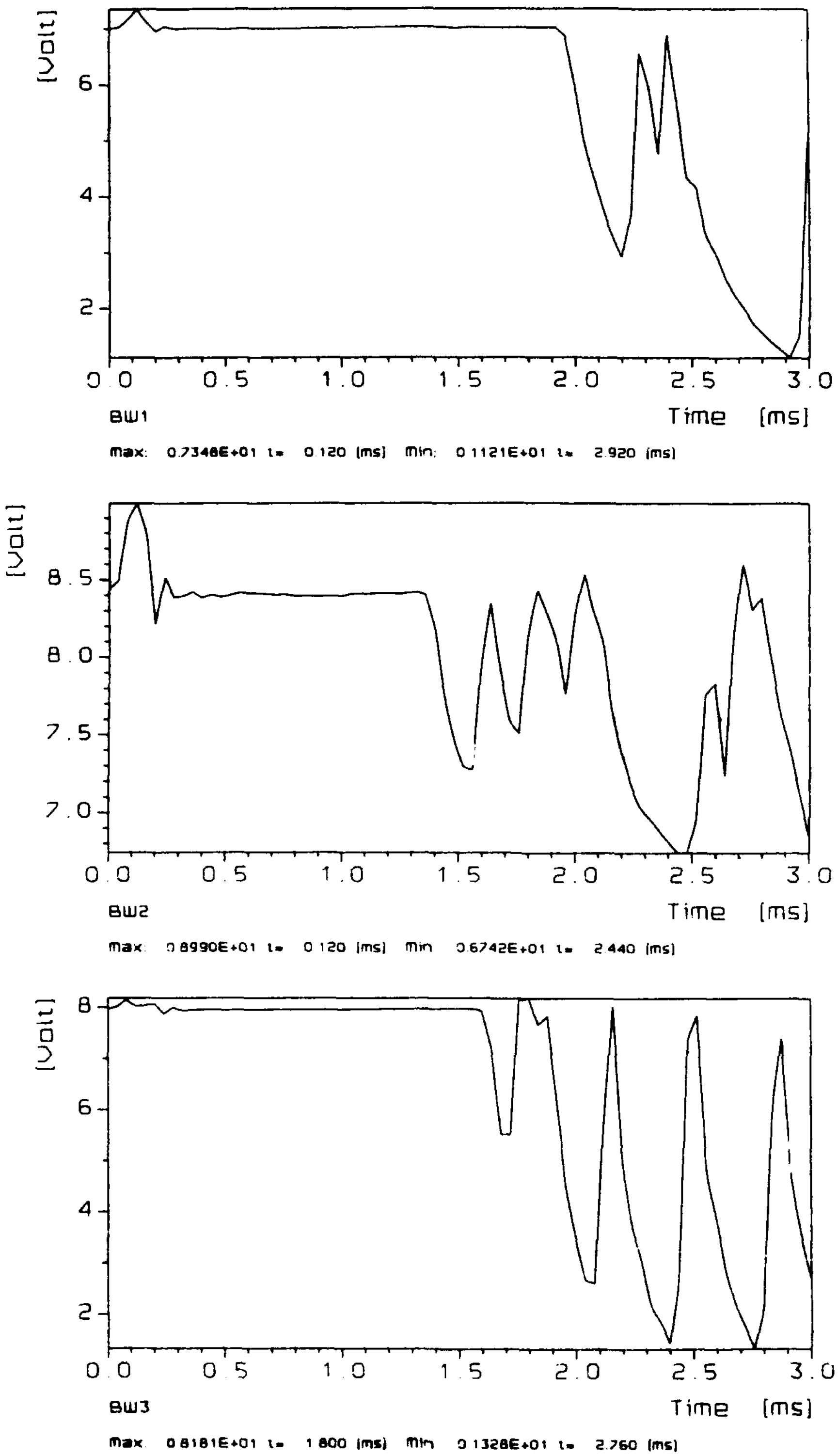


Figure 47 The breakwire signals

9 CONCLUSION

During the Wolf Phase II trial, a number of instrumented experiments in the crew front and aft sleeping compartments were performed. During these experiments, attention was paid to the blast, quasi-static pressure, strain, acceleration, temperature and the possible moment of collapse of the watertight doors.

This report presents the results of the 5.5 kg TNT experiment in the crew aft sleeping compartment. The interpretation of these recording will be the subject of van Erkel (1992).

Preceding the 5.5 kg TNT experiment (as dealt with in this report), the 2 kg TNT experiment was performed on the same day. Later that day the 15 kg TNT experiment took place. It is for this reason that the damage due to the 2 kg TNT experiment (rupture of walls) could not be repaired between the experiments. Moreover, reparation/modification of the instrumentation was not possible. The settings of the instrumentation equipment was based on the expected extreme responses of the 15 kg TNT experiment later that day which had, however, an influence on the signal-to-noise ratio.
Although it is not within the scope of this report, it must be mentioned that during the 5.5 kg TNT experiment, the upper deck was ruptured.

The blast measurements seem to have recorded correctly, although transducer B1 again showed a negative value shortly after the arrival of the shock wave. Discrepancies with theoretical predictions based on a centrally ignited spherical charge are noticeable.

The quasi-static pressure in the experiment compartment as well as in the adjacent compartments showed classical behaviour, although the influence of the ruptures seems to be noticeable from the decay of the signals. The peak pressure measured in the experiment compartment corresponds reasonably well with the theoretical predictions of Baker and Weibull.

The strain measurements seemed to be good although some of them (mounted in the experiment compartment) malfunctioned after some time. A number of the recordings indicate permanent elastic-plastic deformations. Most of the opposite-mounted strain gauges showed 'in-phase' behaviour (longitudal waves). The strain gauge couple glued on the watertight door in BHD 71 however showed an 'anti-phase' behaviour indicating transversal waves.

The acceleration signals were adjusted by 50 Hz for distortion and drift. Filtering these distortion and drift corrections enables the signals to be integrated resulting in velocity and displacement signals. Due to these ad hoc applied signal analysis techniques, the velocity as well as the displacement signals should be handled with care. The undamped (initial, residual and maxima) shock spectra of these recordings are included in this report.

It appeared that temperature transducer T1 registered a reliable signal although this transducer malfunctioned during the previous 2 kg TNT experiment. The T1 as well as the T2 and T3 temperature signals seems to be realistic. The recorded temperature behaviour in the adjacent compartments corresponds with the quasi-static pressure recordings.

Although the watertight doors did not collapse during this experiment, the breakwires did react to the arrival of the shock wave. This may be due to the microswitches used which appeared to be sensitive to shock.

From this it can be concluded that the 5.5 kg TNT experiment in the crew aft sleeping compartment was successfully recorded. This has resulted in a valuable set of data which may be an integral part of the validation of computational prediction models. Additionally, it increased the knowledge of the phenomena occurring during an internal explosion in a frigate.

10 AUTHENTICATION

The realization of the Wolf Phase II trial presented in this set of reports was achieved due to the effort of a number of people from the Explosion Prevention Group: the technicians, Mr. M.W.L. Dirkse, Mr. Ph. van Dongen, Mr. R.M. van de Kasteele and Mr. A.M. Steenweg, who carried out the experiments and processed the results.
We would also like to acknowledge the supporting services of the Royal Netherlands Navy.

Date:

1 april 1992

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Part II: Bare charge experiments in the front sleeping compartment
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Part IV: lessons learned
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(Geïnstrumenteerde beproevingen aan boord van het fregat "WOLF". Wolf II:Meetresultaten van de 5.5 kg TNT beproeving van het manschappen slaapcompartiment op het achterschip .)

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14. SUPPLEMENTARY NOTES

15. ABSTRACT (MAXIMUM 200 WORDS (1044 BYTE))

Within the framework of the research into the vulnerability of ships, an experimental investigation took place in 1989 aboard the frigate "WOLF" of the "Roofdierklasse" (PCE 1604 class) (Wolf, Phase II).

In this report recordings of an instrumented experiment in the crew aft sleeping compartment are presented.

During this experiment, a non-fragmenting charge of 5.5 kg TNT was initiated.

16. DESCRIPTORS	IDENTIFIERS
Frigates	Pressure Measurement
Vulnerability	Strain Measurement
Experimental Investigation	Accelerometers
TNT	Temperature Measurement
Explosion Effects	
Blast Measurement	

17A. SECURITY CLASSIFICATION (OF REPORT)	17B. SECURITY CLASSIFICATION (OF PAGE)	17C. SECURITY CLASSIFICATION (OF ABSTRACT)
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED

18. DISTRIBUTION AVAILABILITY STATEMENT	17D. SECURITY CLASSIFICATION (OF TITLES)
Unlimited Distribution	UNCLASSIFIED

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